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The Journal of
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SURGICAL REHABILITATION OF THE HAND AND FOREARM DISABLED BY POLIOMYELITIS *

BY C. E. IRWIN, M.D., AND D. L. EYLER†, M.D., WARM SPRINGS, GEORGIA

From the Georgia Warm Springs Foundation

Surgical rehabilitation of the hand and forearm received a great stimulus from the outstanding work done on traumatic lesions in World War II. The surgical techniques so well established for reconstruction of the hand after traumatic lesions apply equally well to the poliomyelitic hand.

Certain conditions present in poliomyelitis, which are not always present in the traumatic hand, are favorable to both the patient and the surgeon. Other conditions, however, make rehabilitation of the poliomyelitic hand more difficult and more uncertain.

Among the favorable conditions are: (1) good skin and subcutaneous tissue, (2) normal sensation, and (3) good mobility of the joints.

Scarring and loss of skin rarely present a problem in the evaluation of poliomyelitic patients and sensation is always normal. If the patient has had the benefit of proper splinting and adequate physical measures during the convalescent stage of the disease, mobility of the joint is usually good; however, if mobility of the joint is impaired, or if contractures are present, these should be corrected before tendon transfer.

Conditions which make successful rehabilitation of the poliomyelitic hand more difficult are: (1) disseminated muscle weakness, (2) substitution patterns, and (3) involvement of the trunk and other extremities. Since these conditions are frequently found in poliomyelitis, they will be discussed in detail.

Disseminated Muscle Weakness

The greatest single obstacle to successful rehabilitation of the hand and forearm disabled by poliomyelitis is the completely haphazard pattern of paralysis, which makes a correct muscle analysis difficult in many instances. Two muscles whose individual power may be 50 to 60 per cent. of normal strength may act together as a functioning unit, yet neither may have adequate power to make it a candidate for transfer; of this the radial extensors of the wrist are a good example. A muscle used for transfer should have at least 85 per cent. of normal strength. In addition, tendinous interconnections often exist between such important muscle motors as the radial wrist extensors, so that individual evaluation is impossible. Whenever possible, the muscle belly should be inspected before tendon transfer.

A second factor to be considered is the choice of muscle motor for a given function. In peripheral-nerve lesions, if the innervation of a muscle has remained intact, the strength of that muscle remains normal. When this muscle is transferred, it can be expected to function as a normal transfer in its new position. In traumatic lesions the transfer of muscles with intact nerve supply is more or less standardized — for instance, transfers

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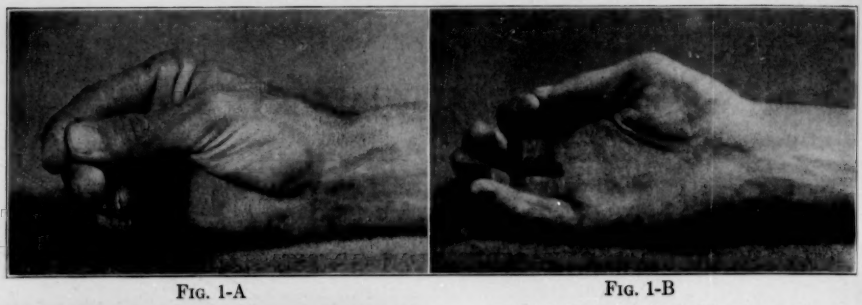

FIG. 1-A

FIG. 1-B

FIG. 1-C

Fig. 1-A: Normal pinch. Note the position of the pad of the distal phalanx of the thumb in relationship to the fingers.

Fig. 1-B: Apposition or false opposition secondary to loss of intrinsic muscles of the thumb.

Fig. 1-C: Substitution pattern: Lacking effective pinch because of loss of power in the intrinsic muscles of the thumb, the patient substitutes by grasping objects between the thumb and second metacarpal.

Fig. 2-A: The patient has lost the intrinsic muscles of the thumb. Note the direction of pull of the extensor pollicis longus in its normal path around Lister's tubercle.

FIG. 2-A

FIG. 2-B

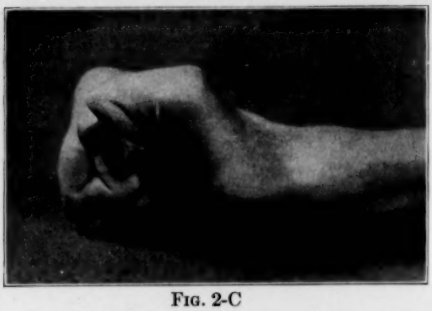

FIG. 2-C

Fig. 2-B: Illustrates partial subluxation of the first carpometacarpal joint resulting from attenuation of the capsule.

Fig. 2-C: The cocked position of the thumb. With the thumb in this position, the capsule and volar accessory ligament become shortened and thickened, with resultant contracture of the interphalangeal joint of the thumb.

for radial palsy. It is often possible to choose a motor with the proper excursion and muscle mass to serve a different function. In poliomyelitis, where paralysis does not follow a definite pattern, available muscle motors may not always be suitable for correcting the loss of function, and compromises must be made. It is often necessary to transfer a variety of muscle motors—for example, a flexor, an extensor, and a long supinator (the brachioradialis)—to restore the loss of a single function such as extension of digits.

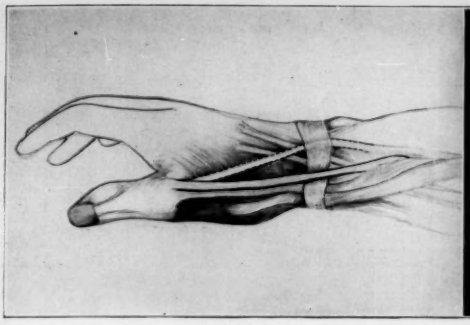

FIG. 3-A

FIG. 3-B

Fig. 3-A: The extensor pollicis longus rerouted in a position more radial than it previously occupied.
Fig. 3-B: Illustrates the direction of pull of the extensor pollicis longus following the rerouting procedure.

Substitution Patterns

Faulty functional patterns are acquired early and become deeply ingrained. To alter or transfer a unit from a well-established substitution pattern frequently invites disaster. Not only are such transferred muscles often difficult to re-educate, but the function of a critical substitution pattern may be lost by the elimination of one of its units. In this manner the surgeon may lower the patient's over-all function and activities or even interfere with his means of livelihood, even though the surgeon intervened in good faith.

FIG. 4-A

The extensor pollicis longus plays the leading role in the most common substitution pattern seen in the poliomyelitic hand. In the normal hand the extensor pollicis longus is

FIG. 4-B

FIG. 4-C

Fig. 4-A: Pattern of substitution in which the extensor pollicis longus acts as an effective adductor of the thumb.
Fig. 4-B: View of the patient's pinch following transfer of the ring sublimis for opposition and rerouting of the extensor pollicis longus. Shoulder and arm are flail.
Fig. 4-C: The patient's attempt to revert to her old substitution pattern is unsuccessful because, while she can still move her hand across the page with the fingers in crablike fashion, she can no longer cock the thumb firmly against the second metacarpal to hold the pencil for writing.

FIG. 5-A

FIG. 5-B

Fig. 5-A: Failure to rehabilitate the type of deformity seen in Fig. 6 by simple opponens transfer. In an attempt to restore opposition, the ring sublimis was transferred to the base of the proximal phalanx of the thumb and the long sublimis to the neck of the first metacarpal. Neither of the transfers, alone or together, has been successful in restoring the function of the thumb.

Fig. 5-B: Shows the patient's ineffectual attempt to get the thumb far enough out of the palm to oppose the index finger.

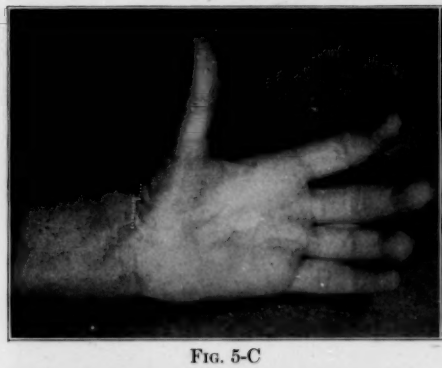

FIG. 5-C

FIG. 5-D

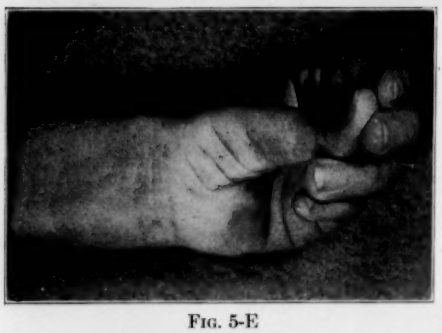

FIG. 5-E

Result after operation

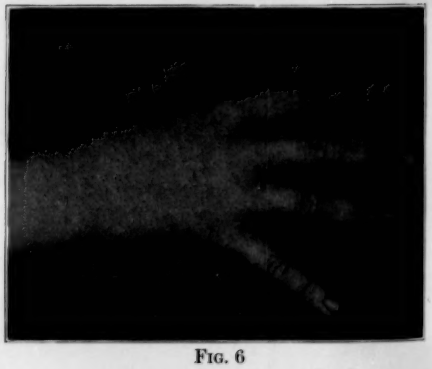

FIG. 6

Fig. 5-C: Ability to extend the thumb following arthrodesis of the metacarpophalangeal joint in flexion of 20 to 30 degrees.

Figs. 5-D and 5-E: Views of the patient's pinch. Note function of the previously ineffective opponens transfers.

Fig. 6: Ulnar deviation of the phalanges on the first metacarpal. This deformity is the result of allowing the pull of the extensor pollicis longus to go unsplinted over a prolonged period of time. The thenar musculature is subfunctional.

an extensor of the thumb or, more strictly speaking, an extensor of the terminal phalanx of the thumb. In the poliomyelitic hand where there is loss of power in the thenar musculature and the adductor pollicis, the patient, lacking effective pinch, substitutes by grasping

FIG. 7-A FIG. 7-B

Simple plastic opponens splint.

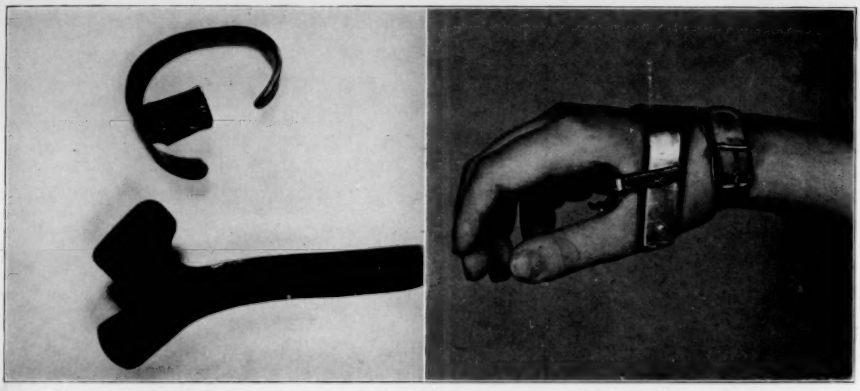

FIG. 7-C FIG. 7-D

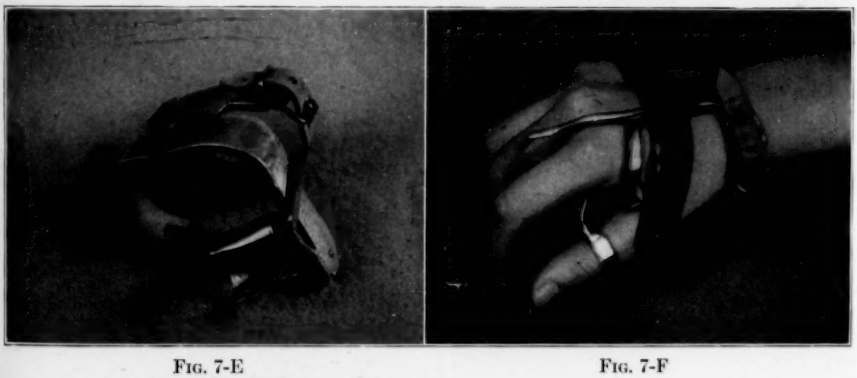

FIG. 7-E FIG. 7-F

Fig. 7-C: Pattern for plastic opponens splint.
Figs. 7-D and 7-E: Metal and leather opponens splint.
Fig. 7-F: Modification of splint shown in Figs. 7-C and 7-D. It is equipped with swivel-type spreader bar to maintain the first web space and with a first dorsal interosseous bar to prevent ulnar deviation of the index finger.

objects between the thumb and second metacarpal. In this substitution pattern the extensor pollicis longus acts as a strong adductor (Figs. 1-A to 1-C).

If this faulty pattern is allowed to remain uncorrected by proper splinting, several deformities occur. The first is attenuation of the palmar portion of the capsule between the greater multangular and the first metacarpal, with resultant partial subluxation. When

such cases are treated by the usual methods of restoring opposition, the thumb often goes into opposition with a cog-wheel type of motion and may revert to the so-called cocked position during grasp (Fig. 2-C).

One method of treating such a deformity is, in addition to transferring the opponens, to reroute the extensor pollicis longus. The extensor is removed from its normal path around Lister's tubercle of the radius and rerouted subcutaneously in a position more radial than it previously occupied[5]. Postoperatively there is less tendency to cocking of the thumb, and the rerouted extensor pollicis longus is removed as a deforming factor, and is also in a better position to strengthen the frequently weakened abductor pollicis longus (Figs. 3-A and 3-B). Arthrodesis of the carpometacarpal joint of the thumb for subluxa-

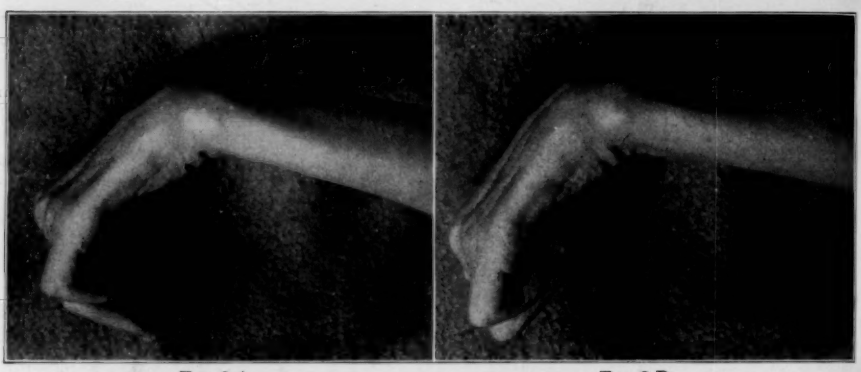

FIG. 8-A FIG. 8-B

Extension and flexion before the operation.

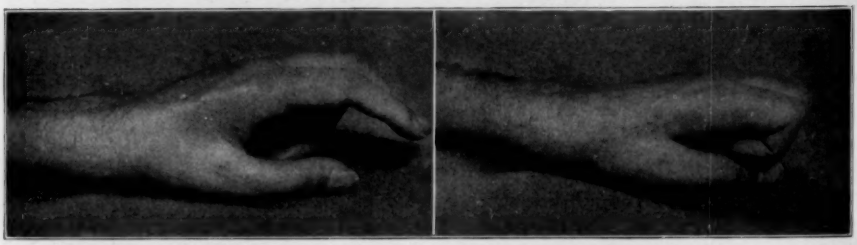

FIG. 8-C FIG. 8-D

Extension and flexion after operation. Patient is able to extend the middle and distal phalanges of the index and long fingers, using intrinsic muscles which have 50 per cent. of normal function. The metacarpophalangeal joints of the ring and little fingers were not arthrodesed because the intrinsic muscles were of insufficient power to extend the two distal phalanges when the metacarpophalangeal joint was stabilized.

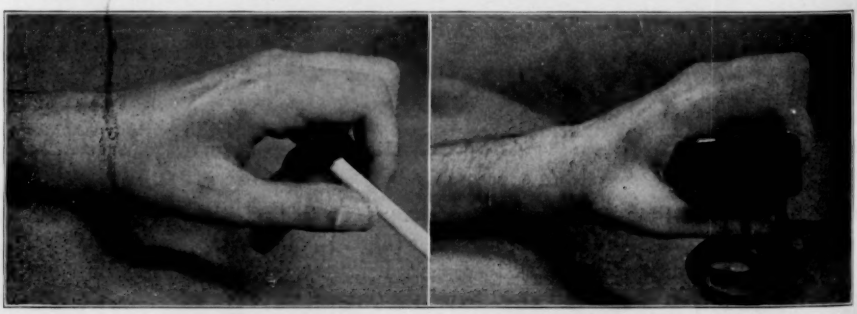

FIG. 8-E FIG. 8-F

Showing the patient's pinch and grasp.

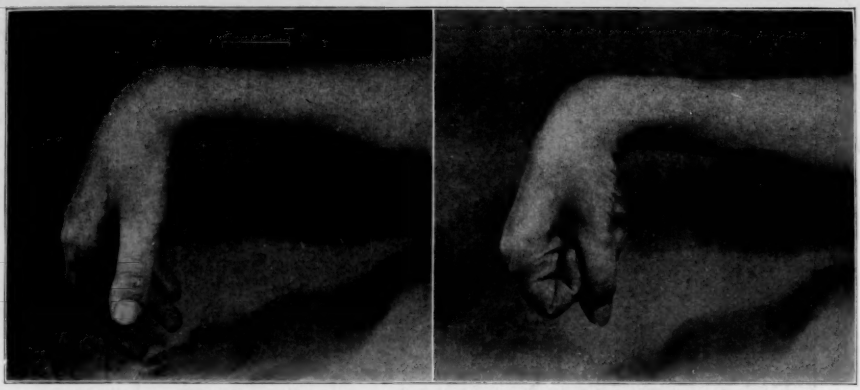

FIG. 9-A FIG. 9-B

There are extension and flexion without stabilization.

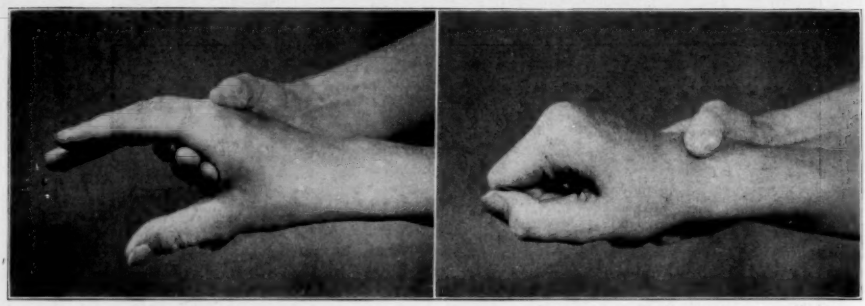

FIG. 9-C FIG. 9-D

Fig. 9-C: Extension is possible when the wrist and the metacarpophalangeal joints are manually stabilized.

Fig. 9-D: Showing the patient's grasp when the wrist is manually stabilized. The patient has no power in the wrist flexors but good power in the finger flexors and all intrinsic muscles.

tion is to be condemned. Much of the rotatory ability of the thumb ray is sacrificed by such a procedure.

One must avoid the tendency to catalogue deformities. Although the need for surgery in two cases may seem identical, careful functional tests may reveal certain important differences. A patient with a flail shoulder and arm, and a weakened forearm and hand, may find the substitution pattern under discussion better than "normal pinch". Figures 4-A to 4-C illustrate one such case. This patient grasped a pencil between the thumb and second metacarpal and was able to write legibly by using the remaining digits to move the hand across the page in a crablike fashion. After an opponens transfer and rerouting of the extensor pollicis longus, the patient had an adequate pinch; but, while holding the pencil between the thumb and index finger, she was no longer able to write, because she had insufficient power in the ring finger and little finger to move the hand across the page. To make matters worse, when the patient reverted to her old substitution pattern, she was no longer able to write. Although she was able to move the hand in the original crablike fashion, we had, by rerouting the extensor pollicis longus, so lowered its power of adducting the thumb as to render the old substitution pattern ineffective. The patient was no longer able to grasp the pencil firmly enough between the thumb and second metacarpal to write in a legible fashion.

A second type of deformity occurs if the hand is allowed to go unsplinted or untreated over a prolonged period of time (Figs. 5-A, 5-B, and 6). In addition to subluxation of the first carpometacarpal joint, there is displacement of the tendon of the extensor pollicis

FIG. 9-E

FIG. 9-F

FIG. 9-G

Illustrates the range of wrist motion necessary in order that the patient can use the power remaining in the finger flexors for wheeling his chair.

FIG. 10

The patient is able to bear his entire weight on the fully extended forearms. Both triceps muscles are below a functional level.

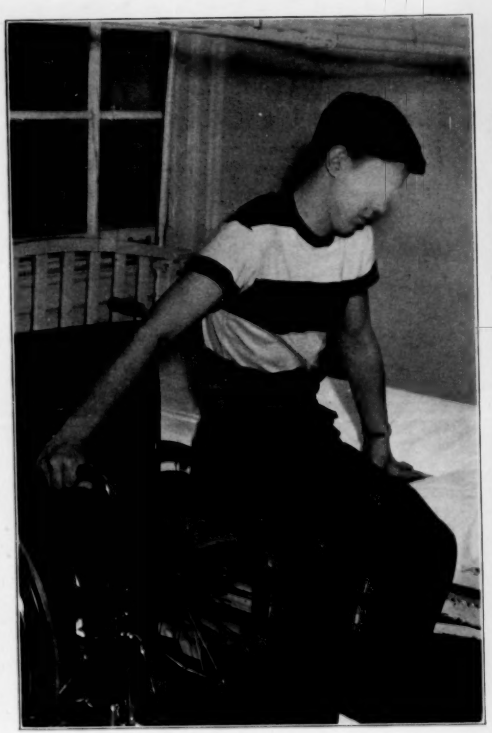

FIG. 11

Patient on fully extended forearms shifting his position from chair to bed.

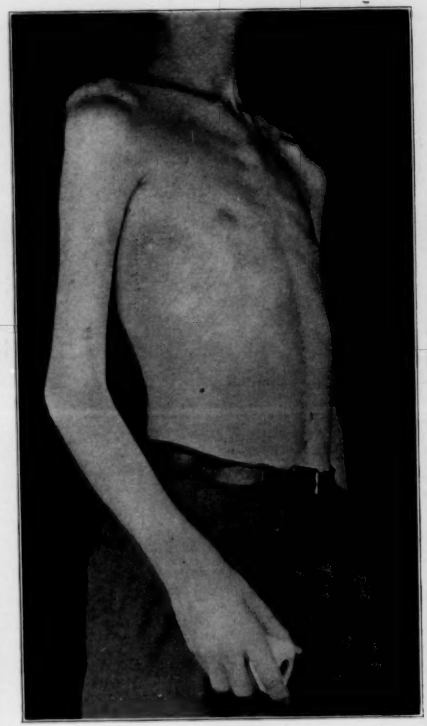

FIG. 12

The residual flexion contracture following Bunnell's modification of the Steindler flexorplasty will restrict to the wheel chair the crutch walker who has a weak triceps.

FIG. 13-A

FIG. 13-B

Assistive apparatus used to improve the function of a patient with an essentially flail upper extremity.

longus into the thumb web, as its oblique pull remains unopposed. The capsule of the radial aspect of the metacarpophalangeal joint becomes attenuated, and ulnar deviation of the phalanges on the metacarpal results. After the deformity has progressed this far, the extensor pollicis longus acts more and more as an adductor and less and less as an extensor of the thumb. To attempt to rehabilitate a thumb with two unstable joints by dynamic transfers alone invites failure. Excellent results may be obtained by arthrodesis of the metacarpophalangeal joint of the thumb in flexion of 20 to 30 degrees in addition to an opponens transfer and rerouting of the extensor pollicis longus. Figures 5-C, 5-D, and 5-E show the results after operation.

The third deformity resulting from failure to correct this faulty pattern by splinting is flexion contracture of the interphalangeal joint of the thumb. With the thumb in a habitually cocked position the capsule and volar accessory ligament of the interphalangeal joint of the thumb become thickened and shortened, resulting in limitation of extension of this joint (Fig. 2-C). It is often necessary to arthrodese this joint in slight hyperextension in order to rehabilitate the thumb.

There are many types of splints with which the patient may be fitted during the convalescent stage of the disease to combat deformity. Two types are illustrated in Figures 7-A to 7-F.

Involvement of the Trunk and of Other Extremities

In no other field where rehabilitation of the hand and forearm is a problem is the danger of "examining the patient's hand through a hole in the blanket" so great as it is in poliomyelitis. Before surgical intervention the patient's needs and potentialities must be carefully assessed. Each daily act must be evaluated, and the surgeon must consider whether the patient will be ambulatory without the aid of apparatus, ambulatory with the aid of crutches, confined to a wheel chair, or will use both crutches and a wheel chair.

From the point of view of saving what function remains, arthrodesis is a very effective procedure in certain carefully selected cases. Figures 8-A to 8-F show preoperative and postoperative views of the left hand of a patient who is confined to a wheel chair. He is unable to wheel his chair, or to get into or out of it without assistance. Both lower extremities are flail, his trunk is poor, and both shoulders and upper arms are essentially flail. The patient has neither pinch nor grasp in the right hand. The function of the left hand was considerably improved by arthrodesis of the wrist in dorsiflexion of about 30

degrees, of the interphalangeal joint of the thumb in slight hyperextension, and of the second and third metacarpophalangeal joints in flexion of 20 to 30 degrees.

However, hasty and unwise arthrodesis of the wrist may deprive a patient of an important function of hygiene or of the ability to move his wheel chair. Figures 9-A to 9-D show the right hand of a patient who is confined to a wheel chair, unable to stand even with braces, and unable to get into or out of a chair without assistance. Both lower extremities are flail, the trunk is poor, and the shoulders are essentially flail. On the left side the patient has a functioning biceps, and can use the forearm and hand. At first evaluation it would seem that this patient would also benefit by arthrodesis of the wrist and two or more of the metacarpophalangeal joints. However, there is a subtle but important difference between the two cases. The second patient, by making use of all the motor power remaining in the upper extremities, is able to wheel his chair on flat, smooth surfaces in such a manner as to be somewhat independent. When his wrist was experimentally stabilized with a dorsal splint, the patient was no longer able to wheel himself (Figs. 9-A to 9-G).

A flexorplasty at the elbow with residual flexion contracture may permanently deprive of walking the patient who before surgery was a creditable crutch walker (Figs. 10, 11, and 12). Patients with essentially flail upper extremities can be given a greater range of function by the use of such assistive apparatus as balanced suspension feeders (Figs. 13-A and 13-B).

Several investigators [1,3,4] have shown that a muscle paralyzed by the virus of poliomyelitis, if given the benefit of adequate physical measures, will at the end of three months have regained approximately 50 per cent. of its ultimate maximum strength. (This, of course, does not necessarily mean 50 per cent. of normal.) At the end of six months, with proper care, the same muscle will have regained 75 per cent. and in nine months 90 per cent. of the ultimate maximum strength. Improvement continues for an additional six to nine months but reaches a plateau thereafter.

In past years it has been the policy to postpone surgical procedures on the upper extremity until functional patterns have become well established. This was usually twenty-four months or longer following onset of the disease. The present trend at the Georgia Warm Springs Foundation is toward earlier and multiple evaluation and earlier surgical intervention before complex substitution patterns have become established. More patients are being operated upon within the first twelve to fifteen months, and, although it is too early for statistical comparison, the early results are encouraging.

Emphasis should always be placed on doing the simple things first. Restoration of either grasp or pinch as the goal of rehabilitation must depend upon the patient's specific needs. If the patient has a functioning pinch and grasp on one side, every effort is made to improve his grasp on the opposite side.

Technically, the type of surgery necessary to rehabilitate the poliomyelitic hand is not the chief problem. The most important thing is complete and proper evaluation. The surgeon must also learn what not to do, and above all he must avoid considering the mere existence of a deformity as an invitation to surgery.

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REPAIR OF EXTENSOR-TENDON INSERTIONS IN THE FINGERS *

BY H. MINOR NICHOLS, M.D., PORTLAND, OREGON

Injuries to the extensor-tendon apparatus over the dorsum of the proximal or distal interphalangeal joints present a common and often difficult problem in hand surgery. The tendon structure in these two regions is so thin that it may be severed by a comparatively slight laceration, or may be ruptured subcutaneously by forced flexion of the fingers or by a blow from a blunt object. The clinical appearance in either of these injuries is quite typical.

Rupture of the extensor mechanism at the distal joint allows the unapposed profundus tendon to flex this joint, resulting in the so-called mallet-finger deformity. At the same time, the lateral bands of the extensor apparatus retract and the muscle force is transferred to the central slip; this in turn extends the proximal interphalangeal joint so that this joint gradually becomes hyperextended.

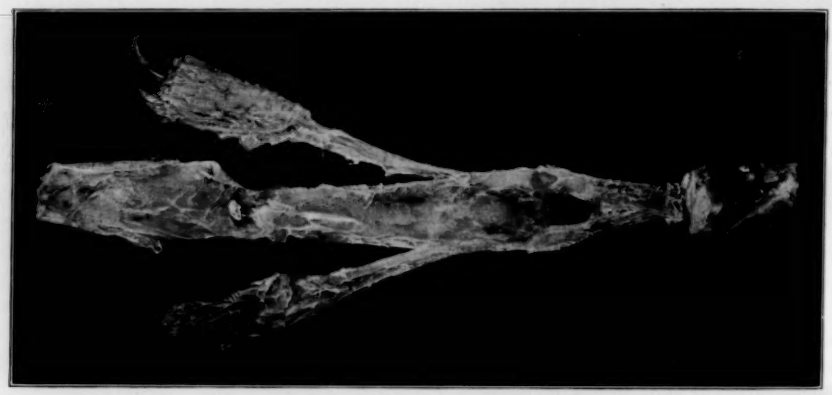

FIG. 1

Palmar aspect of extensor mechanism, taken from the finger of a dissected specimen. The triangular ligament over the interphalangeal joint and the aponeurosis over the metacarpophalangeal joint have been removed to emphasize the tendinous structures. The interosseous muscles and their insertions into the lateral bands are exposed. The two weak areas are: (1) the thin central band just proximal to the triangular ligament, and (2) the thin area just proximal to the distal joint.

Rupture of the central slip over the proximal interphalangeal joint transfers all the pull of the extensor muscle to the lateral bands, which act only on the distal joint. Upon flexion of the finger, the loose attachments between the lateral bands and the central slip are ruptured, so that the joint herniates between them. As the bands spread apart, the triangular ligament is also split. The proximal interphalangeal joint is then held flexed by the volar displacement of the action of the extensor tendon and the distal joint may become hyperextended. The surgical anatomy is illustrated in the photograph of a dissected specimen (Fig. 1).

Surgical repair of either of these injuries by the methods usually described in the literature [1, 2, 3, 4] is often technically difficult and may result in some loss of function.

For fresh injuries the simplest methods available often give good results. For mallet-finger injuries some form of splinting which holds the proximal interphalangeal joint

* Read in part at the Sixth Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 26, 1951, by invitation.

flexed and the distal joint extended may be adequate, especially if the tendon is cleanly cut or if the actual insertion into the bone is torn away. For injuries over the proximal interphalangeal joint, a division of the central slip may sometimes be successfully treated with suture and splinting; if the tendon is avulsed from its insertion into the bone, a drill hole may be made in the dorsal lip of the middle phalanx and a wire passed through to reattach the tendon to its insertion.

If primary treatment is not successful, or if the patient presents himself too late, a reconstructive procedure is necessary to correct the deformity. The principle of the technique to be described is the use of a tendon graft which is anchored where the tendon is fairly strong and bridges the weak area where ordinary sutures would tear out. The primary wound must heal soundly, and an interval of about one month must therefore be allowed to elapse before repair can be undertaken. If infection has occurred, a longer waiting period must be enforced.

The tendon graft used consists of a split portion of the palmaris longus approximately three or four inches long and about the thickness of No. 1 catgut. It is removed through two short transverse incisions over the tendon on the anterior aspect of the forearm and wrist. The tendon is identified, a probe is passed alongside it, and as much of the tendon as is needed for the suture is transected at the upper end, fastened to the probe, and with-

FIG. 2-A

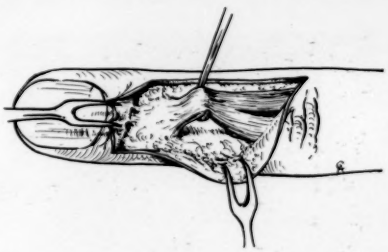

FIG. 2-B

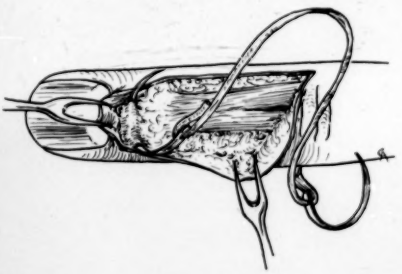

FIG. 2-C

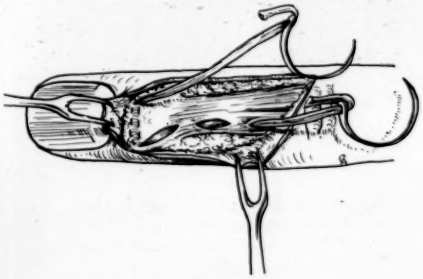

FIG. 2-D

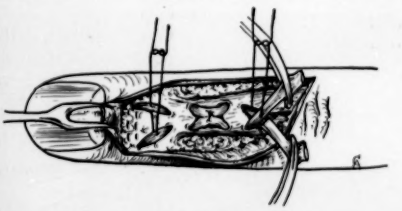

FIG. 2-E

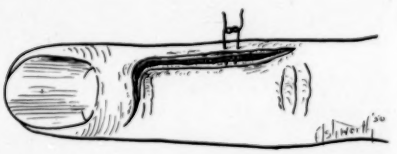

FIG. 2-F

Operation for correction of mallet finger.

Figs. 2-A and 2-B: The incision is made and the flaps are retracted. The scarred tendon is identified.
Fig. 2-C: The tendon graft is anchored distally into dense tissue on the dorsum of the proximal end of the phalanx.
Figs. 2-D and 2-E: The graft is woven into sound tendon proximal to the scar and fastened into place.
Fig. 2-F: Illustrating half-buried mattress suture for closure of the wound. (Drawings made during the operation used in the case illustrated in Figs. 5-A, 5-B, and 5-C.)

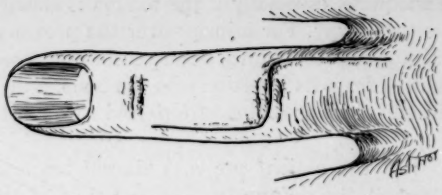

FIG. 3-A

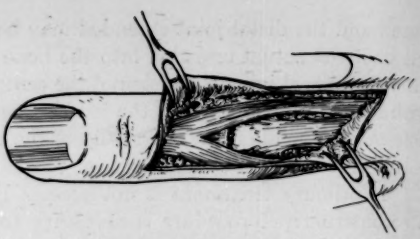

FIG. 3-B

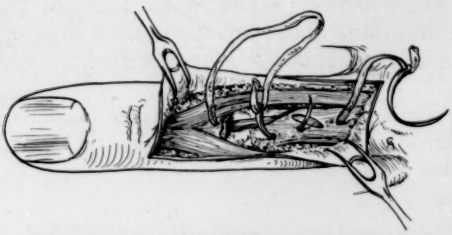

FIG. 3-C

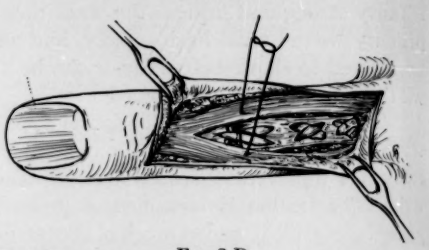

FIG. 3-D

Repair of the central slip over the proximal interphalangeal joint.

Figs. 3-A and 3-B: The incision is made and the flaps are retracted.

Figs. 3-C and 3-D: Showing insertion of graft and position of tendon after grafting. A single suture is used for the triangular ligament.

FIG. 4

Fig. 4: Showing location of drill holes in bone; this method is optional.

Fig. 5-A: Mallet-finger deformity in a man fifty years old.

Figs. 5-B and 5-C: End result in the same patient, showing full function.

FIG. 5-A

FIG. 5-B

FIG. 5-C

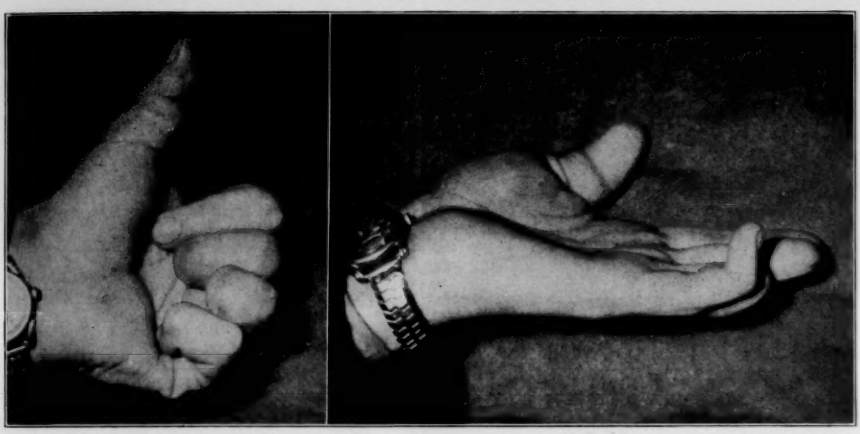

FIG. 6-A FIG 6-B

Mallet-finger deformity in a man twenty-two years old.

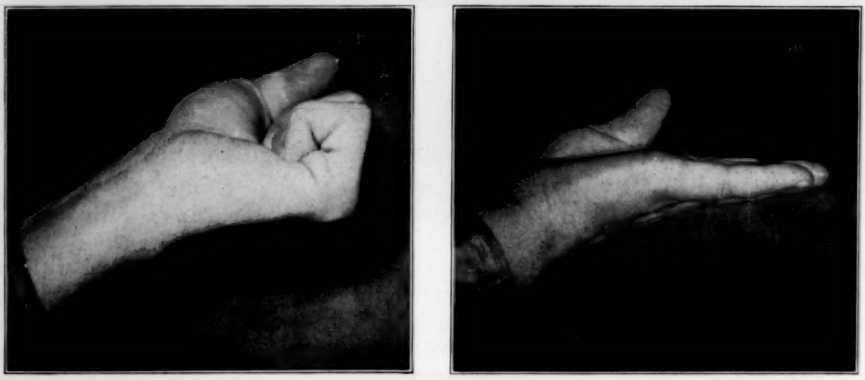

FIG. 6-C FIG. 6-D

Final result, showing full function.

drawn through the wrist. The tendon may usually be split without withdrawing its whole thickness outside the skin. The graft is threaded into a small curved needle *.

The tendon graft is first anchored at the insertion, being passed through the stump of the old tendon or, if one prefers, through a side-to-side drill hole in the phalanx (Figs. 2-A to 3-D). It is then passed back across the joint, threaded through the scarred area, and brought back, being woven into sound tendon proximal to the tear. If the operation is for repair of the proximal interphalangeal joint, the graft is woven only into the central slip of the extensor tendon. Both ends of the graft are woven into good tendon, and the tension is adjusted in such a way that the joints are flexed to the same degree as those of the fingers on each side when the wrist is flexed and extended. The graft is then sutured into place with mattress sutures of fine wire It is usually not necessary to remove the scar tissue which has filled in the gap caused by the injury, or to free the tendon from its surroundings. It is important to obtain the correct degree of tension over either joint so that the finger may flex and extend properly and the graft will not tear loose later.

The usual minute attention to technique is essential in this procedure. A general

* The needle used is a Murphy's hemostatic (Ironarm No. 834), a small round needle, fully curved, with a heavy body, trochar point, and a big eye.

FIG. 7-A

FIG. 7-B

Rupture of the central slip over the proximal interphalangeal joint in a man forty-five years old.

FIG. 7-C

FIG. 7-D

Final result in same patient, showing almost normal function.

anaesthetic is preferable, and the operation should be done in a bloodless field with the use of a pneumatic tourniquet. The skin flaps must be widely reflected and great care must be exercised to avoid injury to the skin or underlying tendon. The nail bed on the dorsum of the distal phalanx must be protected. The dense tissue just distal to the dorsal articulating lip usually affords a good anchor for the graft.

If the skin over the dorsal area is too thin to heal soundly, a flap from the lateral aspect may be rotated onto the dorsum of the finger to cover the tendon graft, the donor area being covered with a skin graft. This procedure may also become necessary when the dorsal skin is badly torn by the primary injury. The lateral bands around the middle joint may have to be freed from the sides of the joint, and the triangular ligament may have to be repaired by a suture (Fig. 3-D). These bands should not be sutured together directly over the joint, as this will interfere with flexion.

In cases where injury to the bone has caused adhesions to the tendons, some sliding material should be interposed between the tendon and bone. The source for this is the elastic tissue between the subcutaneous fat and the deep fascia on the extensor side of the upper forearm.

After adequate hemostasis the skin should be closed, preferably with half-buried mattress sutures (Fig. 2-F). Splinting is essential in order to relax the repaired tendon. After the mallet-finger operation a small padded plaster cast is applied which flexes the proximal interphalangeal joint and holds the distal joint straight. An extension around the distal part of the palm holds the cast in place. For tendon repairs over the proximal interphalangeal joint, a volar plaster splint which holds the wrist and the finger in extension is used. Either of these casts should be left on for about three weeks.

This method is particularly suitable in cases where there are no other defects, where the affected finger has good joints and skin and normal sensation, and where the intrinsic

muscles are functioning normally. It has been used on twelve patients, with success in eleven. In the case where the method failed, the skin had been avulsed by a ring injury and had been replaced by a circumferential flap. Tendon-grafting was followed by infection; the graft was lost; and the deformity recurred. Figures 5-A to 7-B illustrate the early and almost complete return to normal function obtained in the cases with good results.

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METHODS OF TREATMENT OF NEUROMATA OF THE HAND *

BY GORDON H. GRANT, M.D., VICTORIA, BRITISH COLUMBIA, CANADA

The neuroma is not a neoplasm, but is the normal product of repair of the proximal end of a divided somatic nerve. Amputation is commonly followed by temporary sensitivity of the end bulbs of the severed nerves and by phantom-limb sensation. In the majority of patients these symptoms gradually fade and use of the shortened member is resumed with little or no disability.

In a hapless minority of patients the syndrome does not recede. The hypersensitivity of the neuroma increases, bizarre phantom-limb symptoms persist and, in many cases, the disabling cycle of chronic neuralgia and reflex neurovascular dystrophy appears. The purposes of this paper are to inquire again into the reasons why such patients suffer from these sequelae and to recall certain techniques which have been advocated for their prevention or cure.

Histologically, there appears to be no certain clue to the cause. Each neuroma, microscopically, is a proliferating coil of neuraxons and Schwann cells, the whole interlaced with the scar of repair. No inflammatory cellular reaction can be demonstrated in a pernicious neuroma or in the proximal nerve, although there may be a clinical neuritis of the latter as far as it can be traced by palpation. Those neuromata which remain hypersensitive often appear not as fusiform, mobile bulbs, but as stellate plaques, adherent to the scar or periosteum of the stump.

Two major extraneous factors appear to be responsible for the persistence of pain after amputation. One is infection, with resulting excess of scar; the other is a greater or lesser instability of the psyche of the patient. Bunnell has noted that crushing or infection are common factors in the incitation of stump pain. Where too great a length of bone is left, with resulting tension necrosis of the flaps, or where an attempt is made to salvage skin which is devitalized and doomed to necrosis, the result is a prolonged healing period, during which the skin, the terminal arterioles, and the nerve ends become welded to the callus. It may be that the resulting anoxia of the neuroma is one factor in the

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 26, 1951.

persistence of hypersensitivity and pain. Such a stump is likely to provide multiple foci of future trouble. The trapped neuroma, the affected arterioles, and the thickened ligaments are each likely to play a role in production of a variegated neurovascular syndrome. This multiplicity of foci is probably responsible, in many painful extremities, for the puzzling variation in response to therapy directed at the autonomic nervous system.

Weir Mitchell and his associates, in 1864, launched a discussion, which is still going on, regarding the sequelae to amputations, puncture wounds, and severe contusions. Infection was a constant feature of healing wounds in the time of the Civil War and both professional and lay writers have told of the prevalence of causalgia and phantom-limb sensations among the men wounded in its battles. Correct débridement, where applied, and the use of modern antibacterial therapy have greatly reduced but have not abolished these sequelae to wounds of modern war and industry.

Psychic instability has been widely indicted for the persistence of pain after amputation. It is difficult here to separate cause and effect. Persons who are maladjusted sometimes display various abnormal vasomotor and sudomotor phenomena quite apart from the injury. They have cold clammy hands, and they perspire freely and faint under psychic stress. Amputation for these persons causes a more than normally severe psychic shock. Their periods of mourning for the lost limb are prolonged, they refuse to accept their deformities philosophically, and they fail to activate and resolutely use the shortened member. This last may be a vital factor. Even these patients, however, as Livingston [6] has noted, may complain of pain in only one of several stumps or of tenderness in only one neuroma of several in a single stump.

Painful sequelae to amputation also appear in emotionally stable persons, commonly in those whose stumps are badly constructed and scarred. The personalities of these patients are quickly eroded by chronic pain and by loss of sleep. Since they cannot manipulate utensils with their painful hands they are apt to resort to bland diets, with resulting hypoproteinaemia and polyvitamin deficiency. There is still a widespread tendency to label all these sufferers as psychoneurotic, and this attitude, whether overt or covert, simply adds further trauma to the ego of a patient whose miseries may already be driving him to alcohol or drug addiction.

THE MECHANISM OF CHRONIC PAIN

White and Smithwick have summarized the opinions of Stöhr, Sheehan, Leriche, Livingston, and others regarding the nature and routes of the impulse of pain. It is a rough summary of the acute pain sensation generated by trauma in normal tissue to say that it travels over the somatic nerves to the spinothalamic tract and thence to the postcentral sensory convolution. Even this basic pain generates both somatic and autonomic reflexes in the cord, initiating instantaneous muscle action and vasodilatation in the muscles involved.

Chronic pain, whether visceral or sensory, is a compound impulse which has lost its basic warning function and has become itself the chief component of a disease complex. Such pain is usually episodic and may be set off or increased by thermal change, by haphazard trauma, or by psychic stress. Vasomotor and sudomotor phenomena are commonly present. The extremity may be dry, hot, and mottled, or it may be glossy, cool, and atrophic, or clammy and cyanotic. The pain tends to radiate and to spread into fresh somatic fields. It is not within the scope of this paper to define causalgia, reflex dystrophy, phantom-limb sensation, and post-traumatic osteoporosis. It is becoming clear, however, that, while they are separate entities, any combination of them may be present in a limb which has undergone diffuse injury and that each appears to be activated by specific foci.

So far as we know, these chronic impulses still travel over the somatic pathways. No afferent sympathetic pain fibers have been demonstrated. Holden notes that spinal anaesthesia, which blocks the somatic channels but not the lumbodorsal sympathetic chain,

abolishes chronic pain from a leg or foot for an appreciable period of time. Yet neurectomy of a peripheral nerve rarely abolishes chronic pain for long and may even make it worse, while a single procaine block of the appropriate autonomic area may bring lasting relief. There is increasing evidence, however, that this relief is likely to follow only where the major source of trouble is an affected vascular bed.

It is not clear what role the neuroma plays in the production of phantom-limb sensation, but it is probably the specific focus in the early stages. Early removal of a neuroma may abolish phantom-limb sensation, while later resection may have no effect on either the pattern of the sensation or its severity. There is a wealth of evidence that long-lasting pain from any source tends eventually to make its home in the sensorium. Once this cortical projection has been established, division of the spinothalamic tract fails to do away with the pain. Block or division of the sympathetic area may produce the appropriate vascular and sudomotor change without effect on the pattern or severity of the pain.

LOCAL MANAGEMENT OF NEUROMATA

Various techniques have been advocated for dealing with the nerve ends during primary amputation. The need for prophylaxis may be summed up by stating that chronic pain rarely follows a primary amputation in which the nerves are cleanly divided and allowed to fall back into mobile, well-nourished tissues and in which the flaps heal by first intention.

Boldrey[1], in 1943, advocated burying the nerve ends in holes drilled through the cortex of adjacent bone. In a recent communication [2] he states that he has continued to use the method with excellent results and still regards it as the method of choice. The writer has not used this technique. For a time we routinely fashioned a cuff of sheath and ligated this over the ends of the fibrils, but we have noticed no especial variation in results since giving this up.

When the patient is first seen after the amputation, the whole extremity as well as his psychic and nutritional state should be assayed. Psychotherapy and a vitamin-rich diet may do wonders for a patient whose morale is being destroyed by chronic pain, idleness, and malnutrition.

If the stump is tense, with the skin badly vascularized and adherent to bone, it is basically good surgery to remodel such a stump. Demonstrable neuromata should be removed, each with its adjacent block of scar. If the stump is mechanically sound and a neuroma seems to be the source of trouble, it is worth while to do one clean resection of the end bulb. It is important first to anaesthetize the neuroma to make sure that it is the genuine and only source of pain and tenderness. Search of the area after infiltration of the neuroma may reveal that thickened collateral ligaments or apparently innocuous scars are the true foci. The writer has not known procaine block of a neuroma to produce any degree of cure, but infiltration of a thickened collateral ligament, with prompt mobilization of the affected part, may bring dramatic results.

If one adequate revision of the stump, with resection of the neuroma, fails to cure, it is most unwise to repeat the procedure. Many patients, when first seen, have already had several such operations. Each has added its quota of scar and vascular disturbance, but—and this is more serious—each failure to cure has added to the patient's demoralization and his conviction that he cannot get well.

Division of the nerve at a higher level, with immediate resuture, was briefly recommended by Leriche. It has been listed as an undesirable procedure by White[12]. Nevertheless, in two cases to be described here it seems to have been successful.

Russell has given an initial report on seven patients in whom a new technique appears to have given satisfactory results. This method has been successful in four of seven of the author's patients; it has failed or could not be applied adequately in three others.

FIG. 1-A FIG. 1-B

Photographs taken in December 1950, seven months after division and end-to-end repair of the median branch in the distal part of the palm.

The technique is that of repetitious percussion. Russell began by tapping the tender areas with a wooden hammer but found that other types of repetitious, endurable trauma worked better than simple percussion in some patients.

This has been true of the patients to be discussed here. Patients soon find the optimum force, duration, and frequency of percussion or massage and develop special methods of their own, such as drumming the tender area against the arm of a chair or the thenar eminence of the other hand. In each of these patients the neuroma was anaesthetized before the first few periods of percussion.

Questioning of a number of patients who had undergone various amputations and had made satisfactory adjustments revealed that some of them had adopted percussion or massage methods of their own and that some of them still used them during changes in the weather or when fatigued. Others stated that they had simply "worked it out". This, of course, is in accord with Bunnell's advice to encourage the patient to work with his affected hand as soon as possible after healing, both to improve the local health of the tissues and to restore psychomotor control over the alienated extremity.

A brief report follows on nineteen patients who suffered more than normal distress after amputation of digits or parts of the hand and in whom, with three exceptions, neuromata could be specifically indicted as a major source of trouble.

The histories of eight of these patients can be summed up by stating that their stumps were badly constructed and that they had hyperaesthetic neuromata. Each was relieved by a single remodeling of the stump, with concurrent resection of any neuromata found.

Two patients had well-constructed stumps but complained of hypersensitivity of neuromata which were fusiform and mobile. In each, infiltration of the neuroma failed to abolish all the pain or all the tenderness in the area. In each, an adjacent focus was found and was repeatedly infiltrated with procaine, with eventual abolition of symptoms. One was a thickened collateral ligament, the other was a plaque of scar on the dorsal aspect of a neighboring joint. The neuromata seemed to lose hypersensitivity concurrently with the genuine foci.

Two patients were relieved by transection and immediate end-to-end repair of the proximal nerve in the palm.

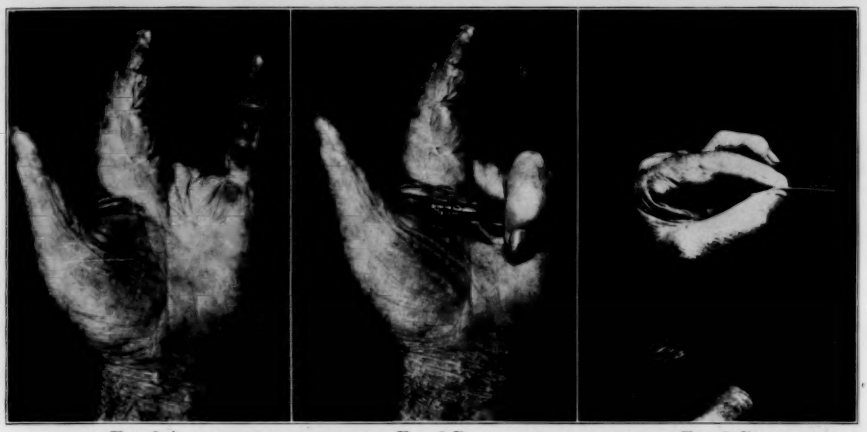

FIG. 2-A FIG. 2-B FIG. 2-C

Photographs taken in December 1950, seven months after initiation of percussion, illustrating the range of digital movement and function of the remaining portion of the hand.

One had undergone three revisions of an index stump with increasing disability after each. His disability was severe. He reported by letter that his stump had become painless and useful after three months and that adequate sensation had returned to the affected half of the digit. The neuroma did not appear to become elongated or again hypersensitive.

The other patient had had five revisions of a ring-finger stump. He had palpable, very sensitive neuromata on both median and ulnar branches on the volar aspect. Percussion seemed to relieve the ulnar side but aggravated the tenderness of the median neuroma and seemed to add a new, dull pain in the stump. Section and repair of the median branch, done in May 1950, seems to have put an end to most of his hypersensitivity and to have relieved a very troublesome jerking of the stump (Figs. 1-A and 1-B).

Four patients have been relieved by percussion.

One patient, forty-two years old, suffered division of the ulnar branch to the ring finger during resection for Dupuytren's contracture in May 1949. The division was recognized and repaired and partial sensation returned to the affected half of the finger, but a small, extremely tender nodule formed in the site of repair, and there was abnormal sweating of the hand. It was proposed to repair again the nerve, but percussion, begun in March 1950, relieved the tenderness for increasing periods and the sudomotor signs receded.

One patient, thirty-eight years old, lost the end of his right thumb by crushing, in June 1947. When seen in November 1948, he had a tight, avascular stump and palpable, very tender neuromata on both median branches. The hand was dry and atrophic and he had pain in the deltoid region and below the right ear. The stump was remodeled and the neuromata were removed. A large neuroma re-formed on the outer branch, his pain returned, and the trophic state of the hand was unchanged. Repeated procaine sympathetic block produced warming and increased mobility of the hand but did not influence either local tenderness or pain. Percussion, begun in March 1950, was carried out five times weekly in the office for four weeks. It was difficult to persuade the patient to keep on, but at the end of that time his symptoms suddenly retreated, and he was able to carry on by drumming the neuroma against the opposite thenar eminence.

A man, sixty-seven years old, suffered gross mangling of the left hand in May 1948. The front of the long finger was transferred to the front of the denuded index finger, and the long finger and ring finger were amputated. There was marked tenderness in the collateral ligaments of the fused proximal joint of the index finger after healing, but this was controlled by repeated infiltration with procaine. A neuroma on the median branch to the lost ring finger developed. This was removed, and the hand was revised in October 1949, without permanent effect on either local tenderness or on pain, which radiated to the elbow and shoulder. There was intermittent cyanosis and clamminess of the hand. This was relieved by sympathetic block, but his pain and local hyperaesthesia were unrelieved and sympathectomy was not considered. Percussion was begun in January 1950. He quickly discovered that he could relieve all symptoms by drumming the tender area with the ulnar edge of the other hand. He still does this daily and the remaining portion of his hand is relatively useful. (Figs. 2-A to 2-C).

A man, forty-seven years old, suffered gross laceration of the left palm in August 1948. An attempt was made to repair the flexor tendons to the ring and fifth fingers in the palm, using tantalum wire. There had been an early Dupuytren's contracture of the hand and, when the patient was seen in March 1949, the entire palmar fascia was very hyperplastic, and the affected fingers were contracted to ninety degrees.

The fascia was completely resected, the dorsal skin of the affected fingers was used to replace the contracted palmar skin, and an effort was made to mobilize the remaining digits by active splinting. One tender neuroma developed on the median branch to the ring finger. Resection of this failed to relieve the local tenderness for long. The hand was cyanotic and oedematous and could not be mobilized. Severe pain in the deltoid region and a left hemicrania developed. Repeated sympathetic block produced warming and drying of the hand but did not relieve the pain. He began to drink heavily and was unemployable. Concurrent sympathetic and brachial plexus block in December 1949 failed to relieve his pain appreciably, and it was concluded that he had suffered a cortical projection of his pain.

Percussion was begun in February 1950. His vasomotor and sudomotor symptoms receded within three weeks. His neuroma has remained slightly sensitive, but he controls this by occasional massage. He has stopped drinking and uses his two-fingered hand with skill (Figs. 3-A and 3-B).

The history of another patient illustrates the potential complexity of the neurovascular pattern of distress after infection and amputation.

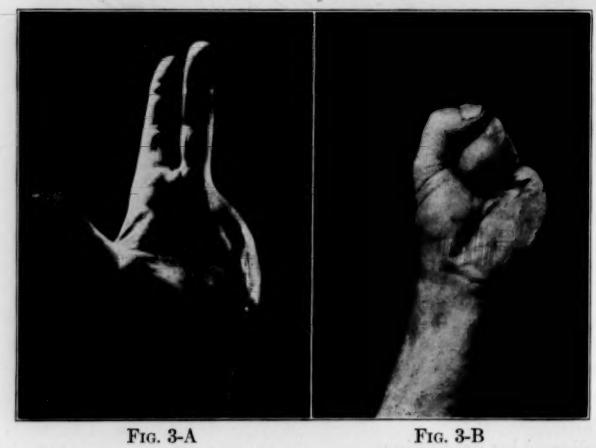

FIG. 3-A FIG. 3-B

Photographs taken in November 1950, illustrating full, painless range of motion of the remaining digits nine months after initiation of percussion.

A woman, fifty-one years old, suffered infection in the right index finger, after a cut by a fish knife in December 1944. Three amputations followed, the last in April 1946, with worsening of symptoms after each. In July 1946, a stellate ganglionectomy was done in Aberdeen, Scotland, with permanent cooling of the hand and production of a Horner's syndrome. Her pain, previously confined to the median field, spread to the ulnar field within three months.

When she was seen in July 1947, the stump was so sensitive that she refused to allow it to be touched. Both the ulnar and the median nerves were exquisitely tender throughout their lengths. The hand was glossy and atrophic.

The head of the index metacarpal was obliquely resected and an adherent stellate neuroma was removed. Her median pain and tenderness were completely and permanently abolished, but that from the ulnar field was unaffected. Sympathetic block produced relief for six weeks after each injection. Dorsal sympathectomy was done in February 1949. The chain broke below the first ganglion, and it was impossible to feel that adequate preganglionic resection had been accomplished. The patient was quite unrelieved. In October 1949, Dr. John Stenstrom resected all identifiable preganglionic fibers and one well-defined ganglion through a transthoracic incision.

The patient has been relieved of constant pain in the arm and hand and her ulnar nerve is no longer tender. She has two trigger points in the depths of the dorsal incision and periodic infiltration of these relieves for long periods a pain which radiates through the scapular region and into the ulnar field (Figs. 4-A to 4-C).

The two last patients, seen briefly in recent months, illustrate the calamitous potential fate of persons whose original troubles are magnified by procrastination and by injudicious peripheral attacks.

One, a woman of forty-five, was a confirmed addict to drugs and alcohol and was a social derelict. An automobile door had been slammed on her hand in 1942. She had undergone an undetermined number of re-amputations and had no ring or fifth finger, and only stumps of the others. She had many tender foci in a dry, atrophic hand. Infiltration and percussion of these failed to help her, and concurrent brachial and sympathetic block did not abolish her pain. She was advised to undergo leukotomy, but she has disappeared.

The other, a man of fifty, was apparently well and stable until 1940, when an infection of the pulp space of the right index finger cost him first the end of that finger and eventually the entire digit and its long neighbor. His hand was dry, cold, and scaly and was not improved by sympathetic block. He had tender nodules at the bases of the lost digits, but infiltration and percussion of these aggravated his symptoms and he refused to submit to further efforts. He died, in November 1950, of coronary occlusion, after a prolonged

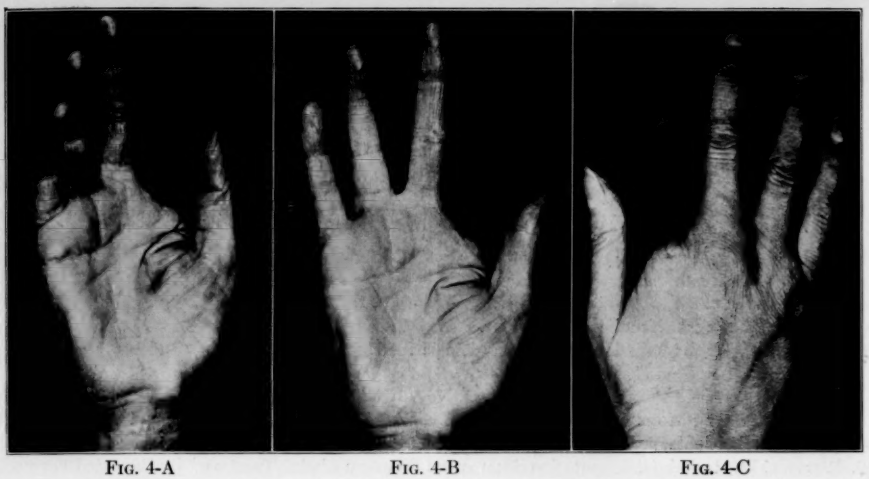

FIG. 4-A FIG. 4-B FIG. 4-C

Photographs taken in September 1950, six years after the original injury.

Fig. 4-A: Showing suggestion of *main en griffe* before infiltration of two trigger points in the dorsal incision.

Figs. 4-B and 4-C: Thirty minutes after infiltration there was complete extension of the fingers.

drinking bout. Since before his disaster he had evidently been only an occasional drinker, he must be listed as a virtual suicide.

It will be noted that sympathetic block in the above patients, with one possible exception, was without effect where the pain could be labeled as having origin in nerve elements. This appears to coincide with the recent views of experienced observers, notably White[14], who states categorically that no form of sympathectomy is effective in amputation-stump neuralgia. It is the author's feeling, however, that procaine block should be given trial in the early stages. The resulting vascular change may not relieve pain of nerve origin, but it may relieve a concurrent dystrophy generated by ancillary foci. Appropriate local measures may then bring complete relief by breaking up the vicious bombardment of the reflex arcs in the cord. Tetra-ethyl ammonium chloride and other chemical vasodilator agents have been ineffectual, in the writer's hands, in the treatment of amputation sequelae.

When stump neuralgia or phantom-limb sensation has been firmly established, only high chordotomy is likely to prevent the establishment of a cortical pattern. White [14] reports unfavorably on the permanence of the benefit from resection of the contralateral sensory area in the postcentral convolution, but he feels that sufficiently high chordotomy, if done in time, will eliminate intractable neuralgia in the upper extremity as it has done satisfactorily at lower levels, in the lower extremity. He shares with Livingston [7] the opinion that radical leukotomy is the only effective means of relieving genuine sensorial pain.

SUMMARY

1. Chronic distress rarely follows a well-performed primary amputation. The proximal nerve ends are probably best dealt with by clean division and recession into mobile, well-nourished tissues.

2. One workmanlike remodeling of a badly constructed stump is advisable, with concurrent resection of any neuromata found. Further procedures of this type are worse than useless.

3. Percussion or massage of the tender area seems to promise much, and many patients discover this of their own accord. The trauma inherent in daily use of the hand is probably helpful in abolishing hypersensitivity and phantom-limb sensation.

4. When well-conceived local treatment fails to relieve, it is vital to turn without delay to the autonomic nervous system. If sympathetic block fails to relieve, it is useless to carry out sympathectomy. High chordotomy should relieve pain if done in time, but procrastination may leave the patient without prospect of relief except through the drastic medium of leukotomy.

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DISCUSSION

Dr. Sterling Bunnell, San Francisco, California: Dr. Grant has given us a clear résumé of this perplexing subject. He has shown that phantom-limb sensation, causalgia, and Sudeck's atrophy are not due directly to painful neuromata but are side effects that may accompany the condition.

Painful neuromata are not cured by sympathectomy, but causalgia is. Phantom limb is not merely a memory in the brain, since the phantom limb may in many cases be modified or removed by excising the scar and neuromata from the amputation stump. Kallio [a, b] has demonstrated this peripheral control in his many cases of Krukenberg's operation. In these the phantom limb also became cleft. Then as the brain acquired a new and unnatural control of the bifid stump, the sensation of a phantom limb disappeared in all except one of his thirty cases [a].

Dr. Grant urged early recognition of a candidate for excessive pain phenomena, and warding off the aberration by early use of the hands or by revising the stumps well and promptly. When after long duration the pain has projected into the cortex, local measures will be of no avail. By novocain injections the location and level of the pain—whether local, in the cord, or higher—may be ascertained.

In the twelve thousand amputees in the Army in World War II, painful stumps were surprisingly few because there was a primary guillotine amputation followed by a revision of the stump in clean tissue. Neuromata which are painful are usually embedded in cicatrix resulting from infection or crushing.

Most painful neuromata yield to a thorough liberal revision of the stump in which the scar tissue is excised so that all is loose and free from cicatrix, and in which the nerves are cut off high and left in good tissue away from where they will be subject to trauma. Ligation, injection with alcohol, or placing the nerve ends in bone in my experience have not helped. Following such a revision, repetitions only tend to drive the pain higher.

After a stump has been revised, the hand should be used freely and worked in. In this it would seem that the percussion method of Russell has its value. It was by walking that the barefoot boy toughened his feet.

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ARTHRITIC DEFORMITIES OF THE WRIST AND FINGERS *

BY ARTHUR STEINDLER, M.D., IOWA CITY, IOWA

INTRODUCTION

Of all the disabilities which develop in the wake of non-specific arthritis, the deformities of the hand and fingers have received the least attention. We may take it for granted that this type of deformity differs in no way from deformities caused by other conditions in that prophylaxis and early treatment take first place in all therapeutic efforts. Reconstructive operations, although they become indispensable in the later stages of the deformity, are less desirable and yield poorer results than conservative measures applied in the earlier stages.

Arthritic deformities of the hand vary in type and degree. Sometimes they develop slowly, sometimes rapidly, but even in the latter case there is time to apply prophylactic measures.

Three principal questions must be considered in the treatment of these deformities:

1. What are the types of deformity and what is the mechanism of their development?
2. What part do the several structures play in producing these deformities?
3. To what extent are they reversible,—that is, amenable to conservative treatment?

As regards the last point, reversibility as a pathological event is reflected by certain clinical signs. The pathological features are the early plastic changes of milder nature: the infiltration of the synovial membranes and of the periarticular structures, accompanying oedema, and effusions. The clinical corollaries are pain in the articulations, rigidity, stiffness, restriction of motion, muscle shrinkage, and atrophy.

On the other hand, irreversible pathological changes are those in which the tissues have reached a biological equilibrium. This is the case in the more extensive destruction of articular cartilage which leads to fibrous or bony ankylosis as well as in the more serious destruction of the joints which causes collapse and telescoping, in the contractures due to the shrinkage of the capsular and fibrotendinous apparatus, and in the relaxation of the capsular apparatus which leads to subluxation and dislocation.

All of these arthritic deformities of the hand and fingers, bizarre and eccentric as they may seem, follow from the beginning a typical pattern of development, so much so that in most instances one can anticipate what type of contracture will be the end result.

THE PATHOMECHANICS

In discussing the part played by the different structures in the development of the deformity, we should distinguish between the skeletal and the soft non-contractile tissues on the one hand and the contractile tissues on the other.

Skeletal Imbalance

The part played by the joints, their capsular apparatus, and their reinforcing ligaments is the primary factor leading to the deformity, since the cartilage and the synovial membrane are the original seat of the pathological changes. The part played by the muscles is secondary.

The Wrist Joint: This joint normally has motion in two planes: flexion and extension and ulnar and radial abduction.

There is normally no pronation or supination of the carpus at the wrist joint against the forearm bones. This motion occurs exclusively between the radius and the ulna and is carried out by the primary pronators and supinators,—namely, the pronator teres and pronator quadratus for pronation, and the supinator brevis and the biceps for supination.

* Presented at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 26, 1951.

FIG. 1

Case J. N. Arthritic flexion contractures of the wrist.

In arthritic hands, one often sees that the wrist is in a pronatory position in relation to the forearm. This position is caused by the accessory pronator,—that is, the flexor carpi radialis prevailing against the extensor carpi radialis longus and brevis as accessory supinators. It can only come about when the natural ligamentous safeguards of the wrist joint have become relaxed by the pathological process. Any such independent movement of the carpus, either in a pronatory or a supinatory direction, must therefore be considered as pathological (Fig. 1).

There is some hardly perceptible pronation and supination associated with ulnar deviation or adduction and abduction of the hand; it occurs mainly in the intracarpal joints where radial abduction is combined with supination, and ulnar deviation with pronation. However, this has no connection with the motion of the wrist against the forearm; it is caused simply by the obliquity of the transverse axes of both the radiocarpal and the intercarpal articulations.

So far as the flexion-extension movement is concerned, the radiocarpal and intercarpal articulations are capable of both flexion and extension under normal conditions; the radiocarpal has a greater range of flexion and the intercarpal articulation has a greater degree of extension. Since the dorsal ligamentous structures of the wrist are much weaker than the volar ligaments, the hand is less well protected against the more powerful volar flexion than against dorsiflexion. Therefore we may expect that contracture of the wrist will develop in a volar rather than in a dorsal direction.

The Carpometacarpal Articulations: In these the motion is so insignificant that it would not be mentioned at all except for the articulation of the fifth metacarpal bone with the carpus. This motion is important for the hollowing of the arch and especially for the opposition of the little finger. In arthritis this mobility may be greatly restricted, and in cases of arthritic synostosis involving this joint it may be destroyed altogether.

The carpometacarpal junction of the thumb occupies a special place. It is a saddle joint with free motion in three planes,—axial rotation, abduction-adduction, and flexion and extension. These are necessary for the circumductory movement of the thumb which requires simultaneous movement in all planes in proper ratio. The axial rotation in the first carpometacarpal articulation has a large range. When the opposition has been completed, the plane of the nail has described 90 degrees of pronatory motion and, at the same time, 45 degrees of flexion and 30 to 45 degrees of abduction.

It is not surprising, therefore, that the carpometacarpal articulations of the thumb show signs of arthritic strain and tenderness even in the early stages. There are strong reinforcing ligaments on the dorsal and volar aspects of the joint capsule; the dorsal ligament checks the opposition and the volar ligament checks the reposition. There are also ligaments to check abduction, but there are none to check the adduction of the thumb. Consequently, the ligamentous apparatus in arthritic hands favors flexion and adduction of the thumb (Fig. 2).

FIG. 2

Case E. B. Arthritic claw-hand. Note the flexion adduction of thumb.

The Metacarpophalangeal Joints: It is in these joints that the most marked deformities occur. The joints also have three kinds of motion,—dorsovolar, lateral, and axial. That the range of flexion is greater than that of extension is apparent from the curving of the metatarsal heads. Lateral motion is small in comparison. Of these three planes of motion, only two are under voluntary control. The third is the movement of axial rotation which accompanies flexion when it is pronatory; in extension it is a supinatory motion.

In arthritic hands when the joint is in either flexion or extension contracture, motion can be carried out only in one plane, and that only incompletely, while motion in the second and third planes is entirely suppressed. Ligamentous checks control the metacarpophalangeal motion. The normal checks of volar flexion are the lateral ligaments which become tight and act as fixation ligaments, and these check lateral motion as well as axial rotation.

In dorsal extension these ligaments relax. The sleeve of the dorsal extensor apparatus, which moves proximally in extension and distally in flexion, has a considerable effect on freedom of motion. The proximal shift of this ligament stabilizes the joint so that it becomes free for the lateral motion by interossei and lumbricales.

In the arthritic joint, we see an early and rapidly progressing fixation of the metacarpophalangeal joints, in a position of either flexion or extension. So far as the capsular apparatus and its ligamentous reinforcements are concerned, the intense shrinkage of the anterior or posterior structure seems to be the principal obstacle to correction of this joint. Muscle contractions appear secondarily (Figs. 3 and 4).

The Interphalangeal Joints: The interphalangeal joints have only one kind of motion; they are the true ginglymus type. Here the restraint of motion occurs through extension of the volar capsular ligament and through the extension apparatus of the finger against excessive flexion. The lateral capsular enforcements are tight in all positions.

The angular values of motion for the proximal interphalangeal joints are normally between 90 and 110 degrees for the fingers and 60 degrees for the thumb. In the arthritic joint, the position may greatly exceed the normal range. This is less evident on the volar than on the dorsal side of the excursion field. In the type of contracture found in the pill-roller hand, there is excessive hyperextension in the middle and distal phalangeal joints. This presupposes a greatly relaxed ligamentous apparatus.

Muscle Imbalance

The muscle contracture which follows the primary changes in the joint constituents and in the capsular apparatus is determined by strictly kinetic factors. In the beginning

FIG. 3

Case G. H. Fixation of the metacarpophalangeal joint.

the contracture is spastic; structural shrinkage follows later; but such structural shrinkage, as a rule, proceeds more rapidly in the joints of the wrist and fingers than in other joints of the body. This condition calls for prompt prophylaxis and early treatment.

The Wrist Joint: The normal pairing of the muscles about this joint is such that the

FIG. 4

Case R. S. Pill-roller hand.

FIG. 5

Case M. K. Ulnar deviation.

range of flexion and extension goes from radiodorsal to ulnar-volar. Consequently, when a flexion contracture develops in the arthritic joint, the joint automatically goes into ulnar deviation (Fig. 5). That the contracture occurs more often in the volar direction can be easily understood when we consider the greater strength of the volar flexors in relation to the extensors.

The constitutional resistance of the patient has a good deal to do with the ease with which the contracture develops. Tightly knit persons offer more resistance to contractures

FIG. 6

Case E. R. Beginning claw-hand.

FIG. 7

Case A. C. Pill-roller hand and hyperextension of the interphalangeal joints.

than do slender patients; the antagonist relaxes more slowly under the increasing tension of the synergist than it does in more loosely knit persons. Again, gravity and habitual attitude are thought by many to be significant factors in determining the type of deformity.

The Metacarpophalangeal Joint: In this articulation the contracture, whether it occurs in the direction of flexion or of extension, presents a disturbance of the normal three-way equilibrium existing between long flexors, long extensors, and intrinsic muscles. The hyperextension contracture is the effect of the overwhelming action of the extensor apparatus (Fig. 6), which prevails against the weak intrinsic muscles. This metacarpophalangeal hyperextension is accompanied by flexion contractures in the middle and distal phalangeal joints. The fingers are closely pressed together, and no lateral motion is possible.

In the flexion contractures of the metacarpophalangeal joint, the condition is reversed. Here the intrinsic muscles are strongly contracted, forcing the fingers into flexion in the metacarpophalangeal joint, and into extension in the interphalangeal joint. Here also, the fingers are closely pressed together so that lateral motion is prevented (Fig. 7).

The ulnar deviation of the fingers, especially of the fifth finger, which is found in the flexion contracture of the metacarpophalangeal joint, deserves special attention. The range of the fifth finger is approximately twice as great in the ulnar as in the radial direction,—that is, about 50 degrees. The index, middle, and ring fingers follow the fifth in its ulnar deviation.

The thumb must be given consideration in cases where the base of the first metacarpal and the greater multangular are involved. This particular deformity was described in detail by Marie and Léri in 1913. In a patient recently seen, involvement of the greater multangular was evident and the x-ray revealed definite destructive arthritic changes as well as bony proliferation. There was pain at the base of the thumb, swelling, and cracking. The abductor and adductor balance was unstable as there was no check to the adduction,

FIG. 8

Case E. G. Pill-roller hand with subluxation.

FIG. 9
Case M. S. Atrophic arthritis. Note multiple subcutaneous nodes.

and the thumb was therefore placed in adduction and opposition. It is particularly in the pill-roller hand that we notice this very marked adduction and flexion contracture.

It is evident, therefore, that all clinical forms of arthritic contractures of the hand and fingers may be grouped into two main types,—the claw hand and the pill-roller hand. In the claw hand, the metacarpophalangeal joints are hyperextended and the interphalangeal joints are flexed. In the pill-roller hand, this situation is reversed; the metacarpophalangeal joints are flexed and the interphalangeal joints are extended. In the one case, we have a weakness; in the other, a contracture of the intrinsic muscles.

The position of the wrist has a very definite effect upon the formation of both types of contracture. In the claw hand, the wrist is in flexion and the passive tension of the extensors of the fingers produced thereby leads to hyperextension in the metacarpophalangeal joints. This again tenses the long flexors of the fingers, with resulting flexion contracture in the interphalangeal joints.

In contrast, in the pill-roller hand (Fig. 8), the wrist remains in extension; the finger extensors are consequently relaxed. In addition, there is the spastic contracture of the intrinsic muscles which are not being opposed by the relaxed finger extensors. The metacarpophalangeal joints become markedly flexed, and the interphalangeal articulations, because of the contracture of the intrinsic muscles, become extended or hyperextended.

Extrinsic Mechanical Factors

While gravity as a contributory element in the formation of arthritic deformities of the hand may be discounted almost altogether, its effect must be taken into consideration once the deformity has been established, although its importance is often overrated. Thus it has been claimed that the position of the hand as it rests on the abdomen is responsible for the flexion deformity and the ulnar abduction in the metacarpophalangeal joint. This is doubtful; it is more likely that the pronation of the forearm and the flexion contracture of the elbow, and particularly the adduction and inward rotation of the shoulder joint, have some relation to positions assumed by the recumbent patient. But so far as the hand and fingers are concerned, the essential cause of the deformity is the skeletal and muscle imbalance produced by the inflammatory process.

EARLY SIGNS OF IMPENDING DEFORMITY

Many times an impending contracture may be anticipated from the rate of development and the type of arthritic symptoms. More often, however, the development of the condition is unpredictable and uncertain, especially since there is no definite relationship between the early clinical symptoms and the tendency to contracture.

Early clinical signs which precede the development of contractures are paraesthesia, tenderness, and swelling. Paraesthesia precedes tenderness; tenderness precedes swelling. In other cases joint destruction may precede contracture. In rare cases subcutaneous nodes appear as early local signs (Fig. 9).

In the roentgenographic studies, regional atrophy precedes joint-space narrowing and the latter again precedes joint destruction.

The roentgenographic changes preceding contracture also vary greatly. They may consist in simple osteoporosis or in subchondral cysts; there may be atrophy and narrowing of joint spaces; or there may be extensive destruction of the joint with complete obliteration of joint spaces (Fig. 10). There is a particular type of atrophic arthritis which leads to early destruction of the carpal bones and early collapse; this is the so-called opera-glass hand (Fig. 11). In such cases, one would expect the contracture deformity to be severe and irremediable. Nevertheless, we find that the deformity may be moderate, and the finger may even show improvement under treatment. This indicates how slowly the contracture deformities develop in some cases of atrophic arthritis.

FIG. 10

Case R. W. Arthritic destruction of the carpus.

Contractures of the wrist and fingers also occur in cases of mixed infections of atrophic and hypertrophic arthritis. In these, one may see the classical Heberden's nodes combined with swelling of the wrist and swelling and contractures of the joints.

PREVENTION AND TREATMENT OF THE DEFORMITY

Under the stimulus of the newer and dramatic remedies for rheumatoid arthritis, one may be confident that the general treatment of this disease is no longer neglected. But their effect, whether they be blood transfusion, the gold treatment, or the adreno-pituitary hormones, depends entirely upon the reversibility of the disease. Furthermore, it has not been proved that even the most potent of these hormonal remedies makes the local treatment dispensable in any phase of the arthritis. On the contrary, under the protection of the general treatment, conservative local measures have become more efficient and promising. The methods are well known: physical therapy, application of heat, paraffin baths, splinting, manipulative correction, active exercises, and much the same policy of reeducation as applies to other localized forms of arthritis. All these remedies have their proper place and their proper time, and it requires good judgment and understanding to allocate them properly and with profit to the patient.

The paraffin baths and whirlpool baths are the most effective means in the stage of swelling and pain and before the development of actual contractures.

Splinting occupies an important place. It is indicated in the beginning stages of contracture. In certain cases in which swelling and pain occur spasmodically and in exacerbation, the result of splinting is sometimes striking.

FIG. 11
Case M. C. Opera-glass hand.

The types of splint devised and recommended for deformities of the different joints are too many to be enumerated here, but they may be classified as follows:

1. Simple retention splints designed to maintain a certain position; they have no corrective effect. An example is the simple rigid cock-up splint for the wrist (Fig. 12).

2. Angulated splints with adjustable hinges or turnbuckle arrangements for step-by-step correction of deformity, such as the hinge splint for the wrist.

3. Spring tension splints. These are angulated splints in which correction is brought about by the continuous action of steel-spring tension (Fig. 13).

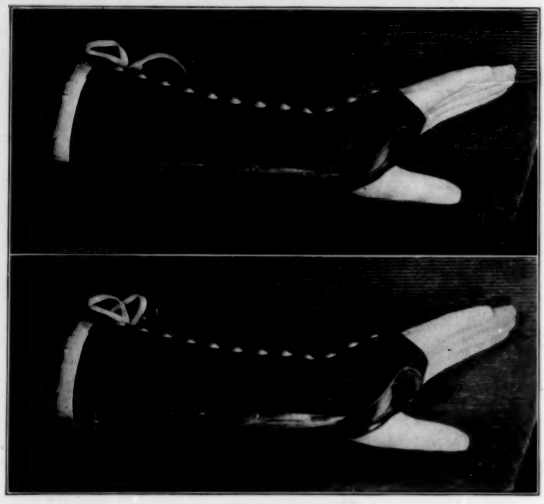

FIG. 12
Cock-up splint for wrist.

4. Elastic tension splints. In these correction is accomplished by the continuous elastic traction (Quengel method) of rubber bands applied at a right angle to the peripheral portion of the joint (banjo splint) (Figs. 14, 15, 16, and 17).

There are certain principles in splinting which should be observed.

The first of these is that a splint should be planned to accomplish only one thing at a time. We have never found it practical to apply a single splint to effect two or three different corrections at the same time. We prefer to use several splints in succession in such a case, each having a single purpose. A splint which is applied to overcome flexion contracture of the metacarpophalangeal joints, for instance, must have a basic portion which

FIG. 13
Spring-tension splint.

consists of a cock-up part to which the banjo ring is attached. On this banjo ring, elastic traction is then applied by means of loops slipped over the proximal phalanges.

The second principle is that the corrective force must be applied at a right angle to the peripheral portion of the contracted joint, and not in line with the axis of this portion. Thus it is a mistake to assume that the banjo splint in itself will accomplish extension of the fingers. The banjo splint is merely a splint carrying a hoop. The direction of the traction must follow sound mechanical principles. To provide stability to the corrective force,

FIG. 14
Elastic rubber-band wrist splint.

the metacarpal joints must be securely immobilized by a bridge which rests under the metacarpal neck. In other words, the mechanical principles of a three-point application must be followed and the force must act in a direction perpendicular to the axis of the phalanx.

In flexion contracture of the interphalangeal joints the same principles apply, but the splint must be specially adapted for the situation. In this case, the proximal phalanges must be stabilized, and the traction must be supplied at a right angle to the middle phalanges.

The flexion contracture of the metacarpophalangeal joints, the so-called pill-roller hand, presents a rather difficult situation. In some instances, there is only a contraction and the proximal phalanges are still in contact with the metacarpal head. In other cases, however, the metacarpophalangeal joint may be subluxated or even dislocated, and ulnar deviation accompanies the deformity in either case.

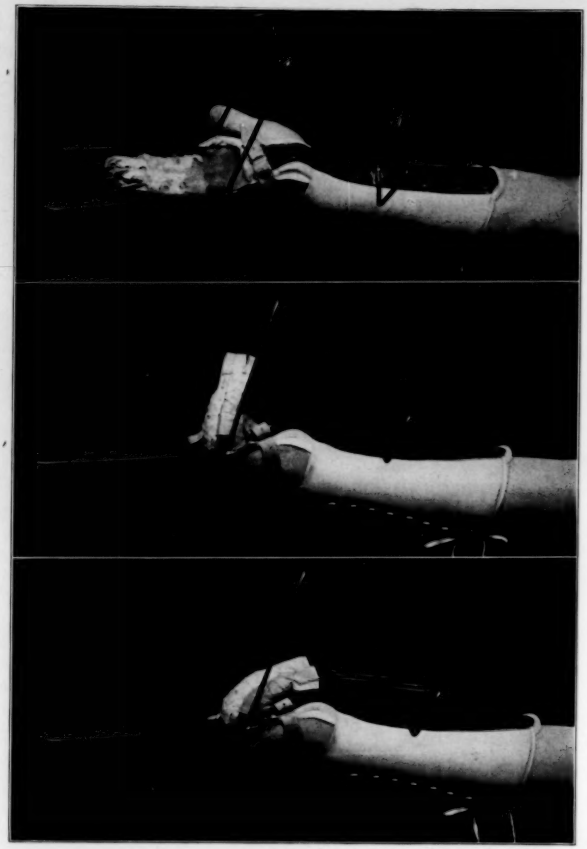

FIG. 15

Banjo splint. Separate arrangement for flexion of metacarpophalangeal joints and extension of interphalangeal joints, applied successively.

The extension contracture of the interphalangeal joint which occurs in combination with the flexion contracture of the metacarpophalangeal joint in the type of contracture found in the pill-roller hand makes the problem somewhat more difficult. However, we must always keep in mind the principle that the proximal portion should be immobilized by a cock-up splint or by a bridge attached to it. In the latter case, it is necessary to secure the immobilization of the proximal phalanges. In this position the corrective force is applied to the middle phalanges and is directed volarly; this is the reverse of the corrective force applied in the flexion contracture of the middle phalangeal joint.

Finally, it should be emphasized that immobilization in splints should never be continuous. Alternation of the splint is important. If the fingers are held in the same position for excessive periods, they easily become stiff. Splints are therefore applied only for certain hours during the day so that mobilizing procedures can be applied during the interval.

Manipulative Treatment

If contractures do not yield to traction, is it permissible to apply manipulation?

We reject forcible manipulation on general principles, both for the wrist and for the fingers. They cause intra-articular hemorrhages, adhesions, and subsequent shrinkage of the cap-

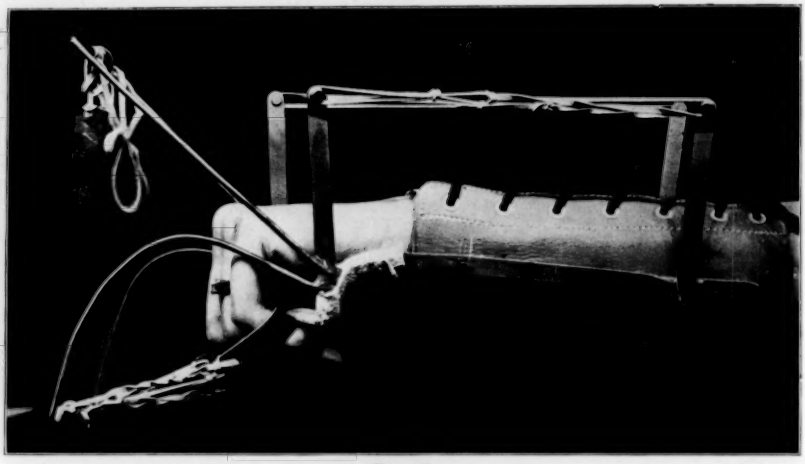

FIG. 16

Correction of contractures by elastic traction with a banjo splint. Although there are two banjo rings, only one is applied at a time. From *Post-Graduate Lectures on Orthopedic Diagnosis and Indications*, Vol. I, by Arthur Steindler. Courtesy of Charles C. Thomas, Publisher, Springfield, Illinois.

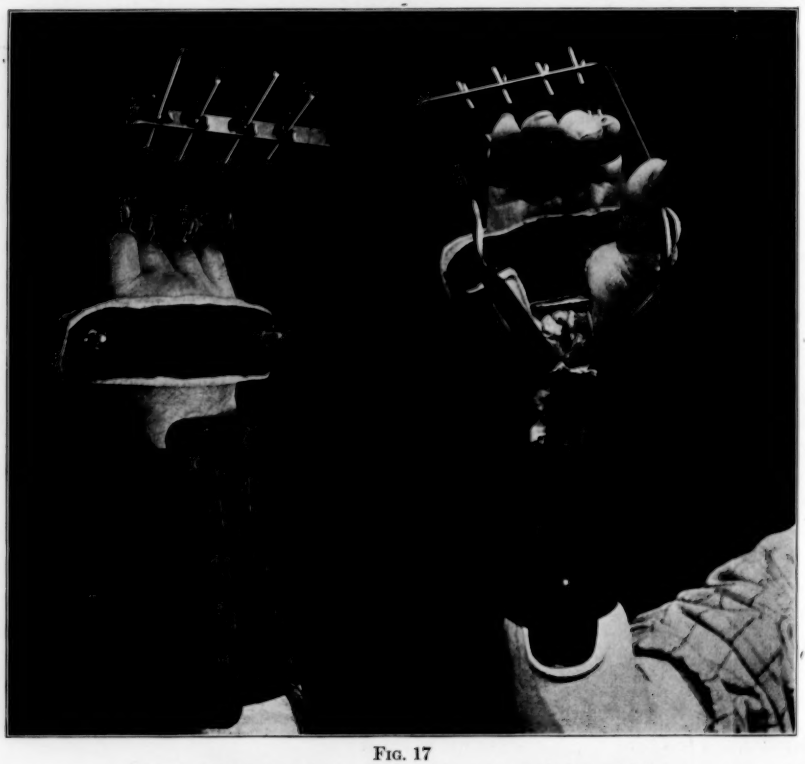

FIG. 17

A banjo splint arranged for extension of metacarpophalangeal joints.

sule. Even passive stretching should never be carried to the point where tenderness or tear of the capsule develops. Stretching should always be gentle, and one should be sure that the connective tissues are not strained beyond their natural elasticity. It is our belief that gentle passive motion and physical therapy accomplish a great deal more than manipulation; we cannot use an occasional successful case as an argument for the latter.

FIG. 18-A

Operative Treatment

There are certain malpositions of the wrist and fingers which must be subjected to operative procedures. In the wrist, an arthrodesis placing the joint in a functionably favorable position is the procedure of choice.

In regard to contractures of the fingers, the situation is a more complicated one. In these, primary attention must be given to the shrinkage of the capsular apparatus. At the metacarpophalangeal joint, the lateral ligament becomes tight in flexion and relaxes in extension.

In flexion contracture of the metacarpophalangeal joint, capsulotomies may be

FIG. 18-B

Fig. 18-A: Case M. W. H. Roentgenogram made after resection of metacarpal heads.
Fig. 18-B: Showing postoperative result in the same patient.

necessary, especially since the anterior portion of the capsular apparatus is heavily reinforced by a fibrocartilaginous plate, the so-called accessory ligaments. In dorsal-extension contractures, the situation is less difficult. In these the problem is only to overcome the dorsal extensory reinforcements of the capsular apparatus, which are less resistant than the volar reinforcements. Once the resistance of the capsular apparatus has been overcome, however, the obstacle of the contracted tendon may remain. With present methods of tendon surgery, the plastic lengthening of the flexor tendons of the fingers within the territory of the tendon sheaths or of Bunnell's "no man's land", is out of the question. Consequently, in severe cases of claw-hand deformity, we prefer to perform operations on the bony structure.

The metacarpophalangeal joints are suitable for arthroplasty. In some cases, it is necessary to remove the metacarpal heads and thereby overcome the irresistible extension contracture of these joints. This is particularly the case when there is already a dorsal dislocation of the proximal phalanges upon the necks of the metacarpals. An operation of this kind is similar to the well-known Hoffman operation which is performed for the extension contractures of the toes (Figs. 18-A and 18-B).

As far as the arthritic contracture of the thumb is concerned, earlier conservative treatment may correct the adduction contracture by a splint with an extra stall which holds the thumb in extension and abduction. In the more severe cases, it may be necessary to immobilize the thumb and make a rigid post out of it through which the fingers can then be approached. In such a procedure, both the carpometacarpal and the metacarpophalangeal joints would have to be arthrodesed.

In conclusion it should be pointed out that, if the management of the arthritic contractures of the hand has not brought us the desired results to date, it is not because we lack adequate operative methods for releasing fully developed contractures. The cause for poor results lies in the failure to recognize the beginning contractures and the failure to take them seriously during the period of their development as well as thereafter. The poor response of the definitely and fully developed contracture to reconstructive operations would imply that a greater field must be conceded to prophylaxis and to early treatment than has been the case heretofore. The writer firmly believes that the solution to this problem lies in the refinement of conservative indications and conservative treatment rather than in a further development of operative methods. That this implies a knowledge of pathological events, as well as an appreciation of the response of tissues to correcting forces, needs no further emphasis.

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THE PRESERVATION AND CLINICAL USE OF FREEZE-DRIED BONE *

BY CAPTAIN F. P. KREUZ, LIEUTENANT G. W. HYATT, LIEUTENANT, j.g., THOMAS C. TURNER, AND LIEUTENANT, j.g., ANDREW L. BASSETT, *Medical Corps, United States Navy*

From the Naval Medical School, Naval Medical Research Institute, and Naval Hospital National Naval Medical Center, Bethesda, Maryland

Orthopaedic casualties have once again become a serious problem. The bone-graft surgery necessary for proper rehabilitation promises to be extensive in many cases. The use of preserved grafts as a means of shortening operative time and convalescence, minimizing surgical shock, and decreasing postoperative pain is receiving careful consideration in selected cases. Bone banks utilizing freezing temperatures and chemicals for preservation are the most popular. However, the expense of freezing equipment, the difficulty in shipping, the change of chemicals, and the frequent cultures necessary for aseptic control combine to make the availability of suitable preserved bone a serious military problem.

Since the economic disadvantages of storage of bone by freezing seem to be paralleled by subsequent clinical disadvantages, it was determined to seek a better method of preservation. It was noted that freeze-drying answered many requirements. The virtue of drying from the frozen state seems to be derived from two factors:

1. Quick freezing at very low temperatures minimizes protein denaturation;
2. Drying from the frozen state lessens harmful concentration of salts as the solid state is maintained throughout dessication[1].

Products which are preserved by drying from the frozen state can be stored at room temperatures and therefore may be shipped in convenient packages without refrigeration. Organic materials such as freeze-dried plasma, commonly known as "lyophilized" plasma, have been demonstrated to be chemically, antigenically, immunologically, and electrophoretically stable immediately after drying and during seven years' storage[2]. Since proteins, enzymes, and vitamins have been preserved by freeze-drying by the pharmaceutical industry, it was postulated that bone tissue could be processed similarly and stored for subsequent grafting.

The procedure consists in freezing the bone and drying it under a high vacuum. In the majority of biologicals the solute remains evenly distributed without becoming concentrated as the frozen solvent sublimates. As a result the dried bone is porous, with a friable, spongelike structure. Cancellous bone crumbles easily, while cortical bone is rigid and inelastic. Both types of bone are reconstituted to normal physical properties in fluid, whether it be saline, plasma, or the patient's hematoma. The process is continuous and can be conducted in the final container in which the material is sealed under vacuum. The average deep-freeze temperature for bone preservation is about −20 degrees to −30 degrees centigrade, and many units have operating temperatures that are even warmer. According to Gersh, about −20 degrees centigrade is well below the freezing point of water containing the normal proportion of body salts[3]. However, even at this and colder temperatures, bone in doubly sealed bottles undergoes some loss of moisture by evaporation. It is conceivable, therefore, that, as the frozen bone tends to dehydrate, the salt concentration in the tissue may be increased sufficiently to lower still further the freezing point of the bone protein. This dessication will tend to denature protein, not only because of the pH change, but also possibly because of the thawing effect achieved by depressing the tissue freezing point below the average deep-freeze temperature. Denaturation (the internal rearrangement of peptide chains which thereby changes the basic physical prop-

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 30, 1951.

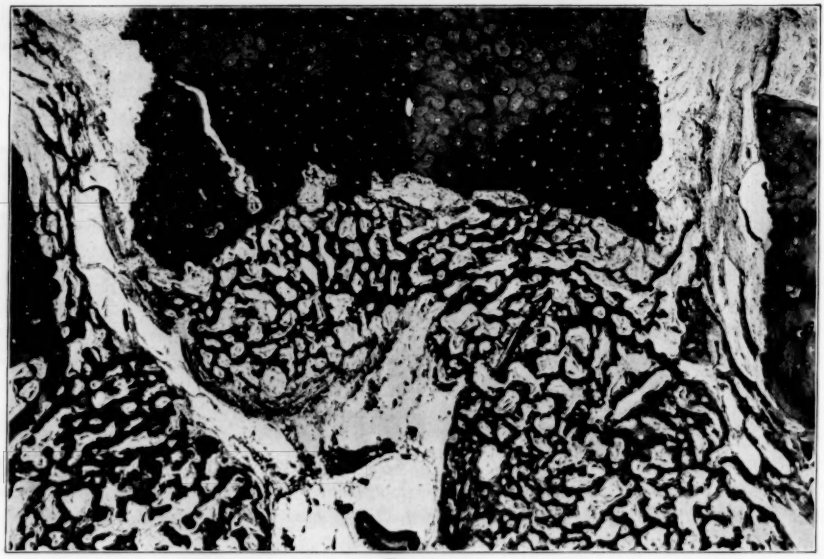

FIG. 1

Photomicrograph (× 14, hematoxylin and eosin stain) of eight-day freeze-dried homogenous graft, demonstrating profuse intramedullary trabecular new-bone formation which is in intimate contact with the graft. *A:* Graft, *B* and *C:* Host.

FIG. 2

Photomicrograph (× 275, hematoxylin and eosin stain) of eight-day freeze-dried homogenous graft, demonstrating intramedullary reactive bone formation against the graft surface.

FIG. 3

Photomicrograph (× 40, hematoxylin and eosin stain) of fourteen-day freeze-dried homogenous graft, demonstrating both intramedullary and periosteal reactive bone formation. *A:* Periosteal new bone, *B:* Intramedullary reactive bone, *C:* Graft.

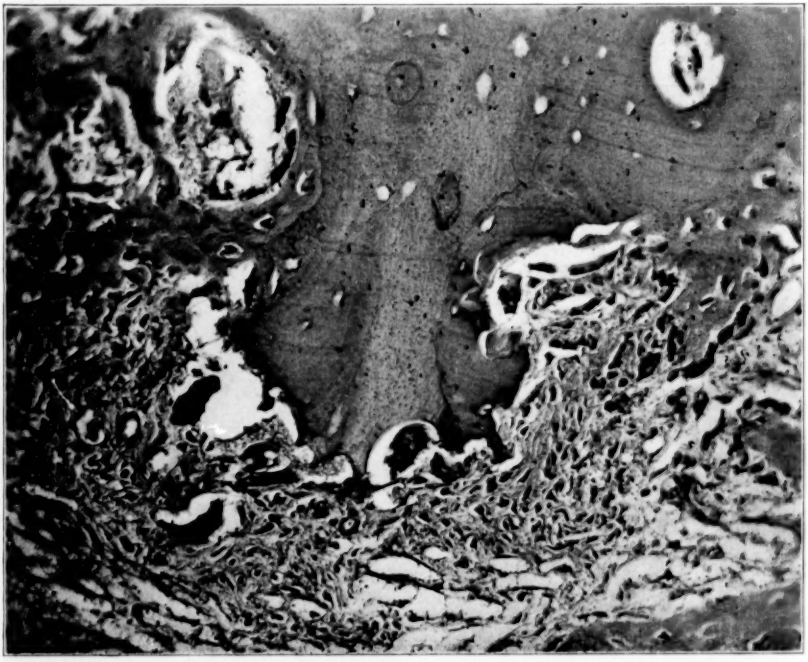

FIG. 4

High-power view (× 275, hematoxylin and eosin stain) of intramedullary reactive bone against graft (magnification of *B* in Fig. 3).

erties of the protein)[6] of osseous protein is considered a factor retarding revascularization of a graft; an example of this is the slow revascularization of a piece of boiled bone.

These factors seem to be corroborated by clinical observations. Wilson observed

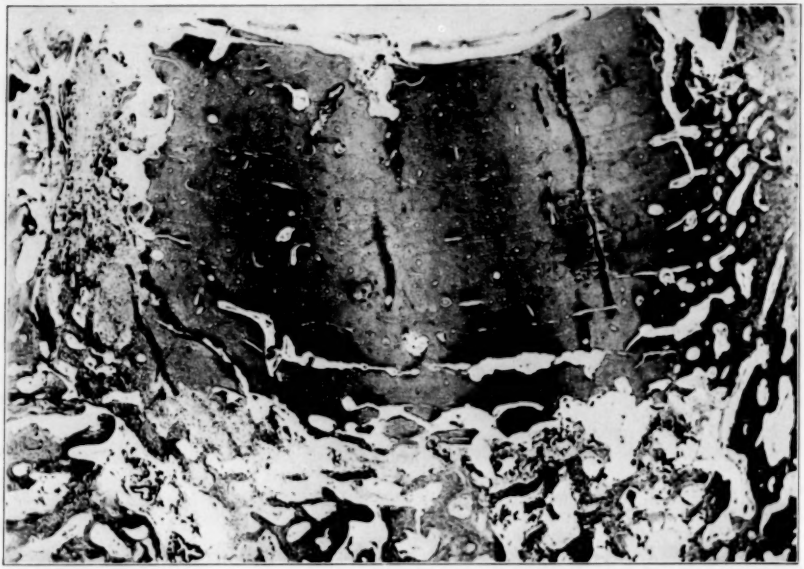

FIG. 5

Photomicrograph (× 14, hematoxylin and eosin stain) of thirty-five-day freeze-dried homogenous graft, demonstrating profuse intramedullary maturing reactive bone.

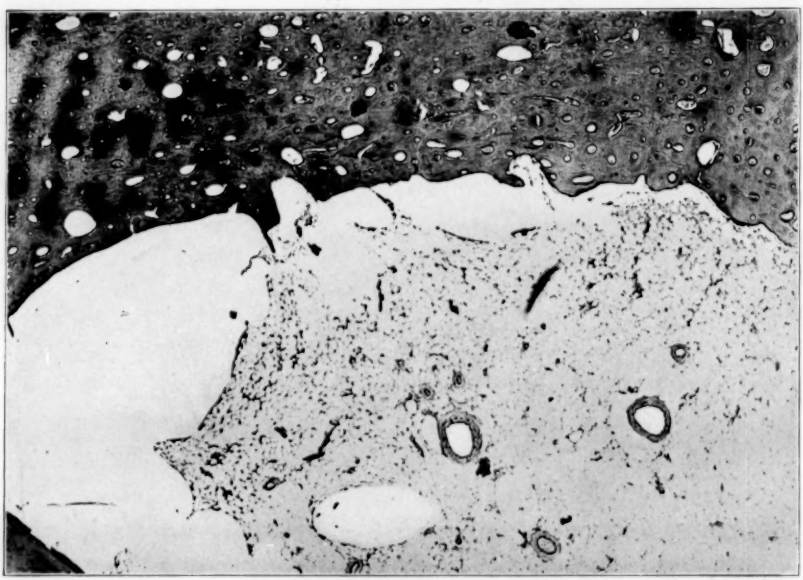

FIG. 6

Photomicrograph (× 14, hematoxylin and eosin stain) of freeze-dried homogenous graft after 150 days. The remodeling is completed; moderate porosity is the only evidence of previous graft surgery.

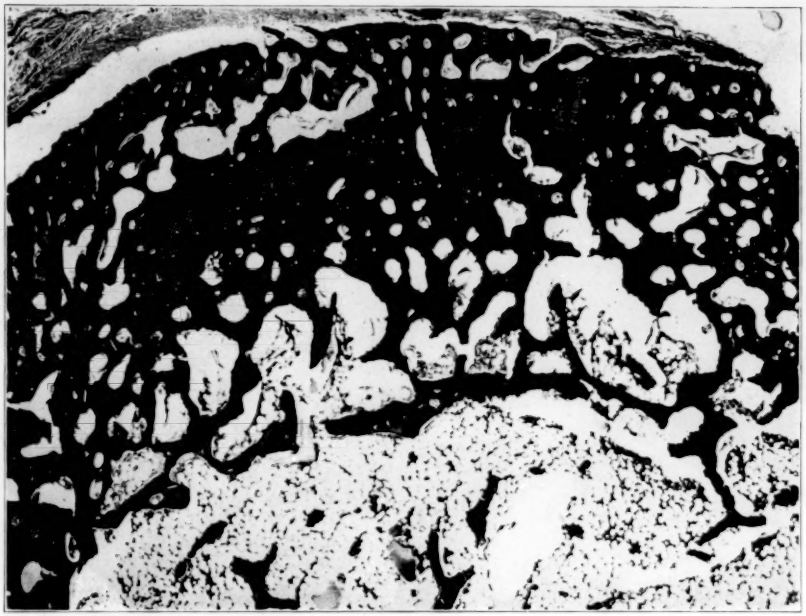

FIG. 7

Photomicrograph (× 14, hematoxylin and eosin stain) of seventy-day freeze-dried homogenous graft, demonstrating confluent vascular channels which have formed a sinusoid in the area of contact between graft and bone.

that frozen bone stored for one year in a single jar does not seem to give as satisfactory a clinical result as bone preserved for shorter periods of time. Speed and Smith noted gross changes,—namely, discoloration, dryness, and loss of elasticity in bone frozen in doubly sealed jars stored for periods as short as three months.

It was decided that study would be devoted to the acceptance and incorporation of freeze-dried bone in animal experiments. The controls consisted of fresh autogenous and frozen homogenous grafts and, in the remaining control animals, of a bone defect the size of the grafts, which was not treated by grafting.

METHODS OF GRAFT PRESERVATION

Freeze-Drying

The technique of drying from the frozen state has been perfected by Flosdorf *.

Freeze-dried bone was prepared by slow freezing at −15 degrees centigrade for four days. Quick-freezing to low temperatures (below −55 degrees centigrade) would have been ideal; however, we did not realize this until the experiment was well advanced. The specimens were placed in dry ice for the eight-hour period of shipment to the proper laboratories. The bone was encased in a block of ice and dried in a Stokes machine under high vacuum at −40 degrees centigrade. The procedure required approximately fourteen days for completion. The shortest approximate storage time was three days, the longest 259, and the average 122 days. This bone was stored on the shelf at room temperature.

Freezing

The frozen bone was stored in single sterile, sealed jars at −15 degrees centigrade. The shortest approximate storage time was five days, the longest fifty, and the average twenty-nine days.

* E. W. Flosdorf, Director, Research and Development Division, F. J. Stokes Machine Company.

FIG. 8

Photomicrograph (× 250, hematoxylin and eosin stain) showing contact site of seventy-day freeze-dried homogenous graft and demonstrating enlarging vascular channels. Note the large cells lining the channel periphery.

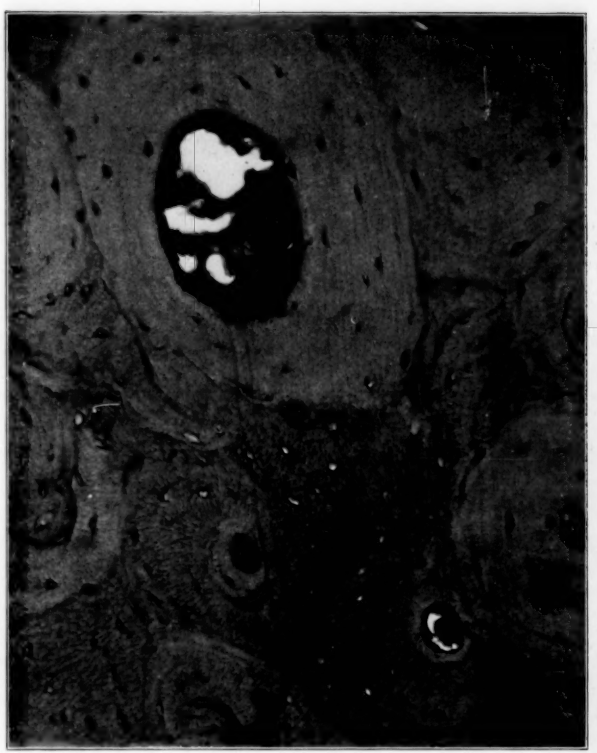

FIG. 9

Photomicrograph (×250, hematoxylin and eosin stain) of freeze-dried homogenous graft after 225 days, demonstrating the concentrically deposited new bone filling the previously dilated vascular channels of the graft.

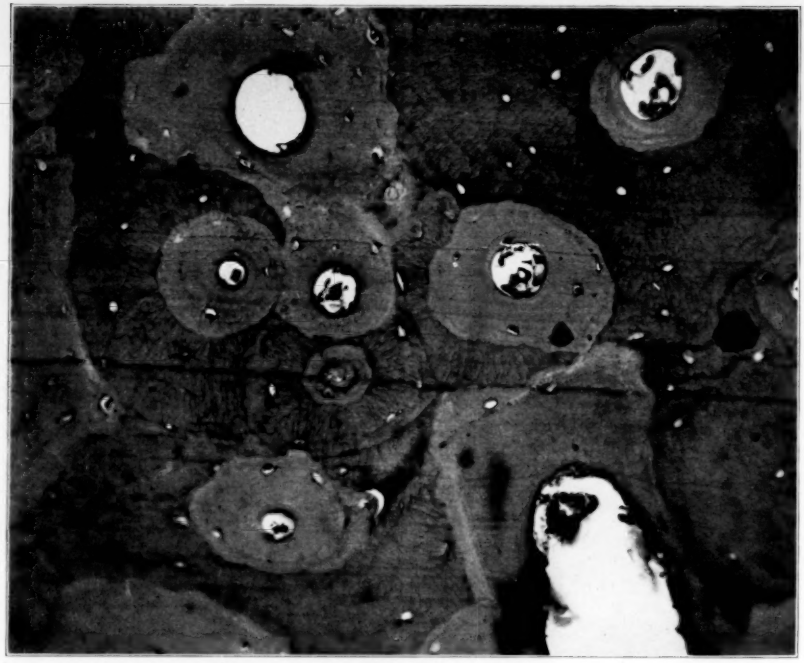

FIG. 10

Photomicrograph (× 275, hematoxylin and eosin stain) of fresh autogenous graft after 287 days, demonstrating new bone filling the previously dilated vascular channels. A considerable amount of dead bone still remains, which will be slowly eliminated by appositional bone substitution, — that is, creeping substitution.

EXPERIMENTAL PROCEDURE

Adult mongrel dogs with an average weight of forty-one pounds were maintained on a standard diet of frozen horse meat and Purina dog chow for the duration of the experiment.

The operative procedure consisted of inlaying a cortical graft into the extensor surface of the mid-shaft of the radius in which a standard-size defect had been made *. The grafts measured 6 to 8 centimeters by 0.5 to 1.0 centimeter. This method secured immobilization without special internal or external fixation. As a control, a fresh autogenous graft was removed and replaced, reversing the direction of the longitudinal axis. No attempt was made to cover the graft with periosteum. As an added control, the standard-size defect was made without implanting a graft.

In the total of forty-four dogs, freeze-dried homogenous grafts were placed in eleven, frozen homogenous in twelve, fresh autogenous in thirteen, and no grafts were used in eight. The animals were sacrificed at about eight, fourteen, twenty-four, thirty-five, sixty, ninety, 120, and 200 or more days.

RESULTS AND INTERPRETATIONS

The response of the host to all grafts has been divided into the following phases:

1. *Reactive Bone Formation:* This is the response of the host to injury and is dem-

* Early operative work was done by Lieutenant, j.g , A. G. Marrangoni, Medical Corps, United States Naval Reserve (Inactive).

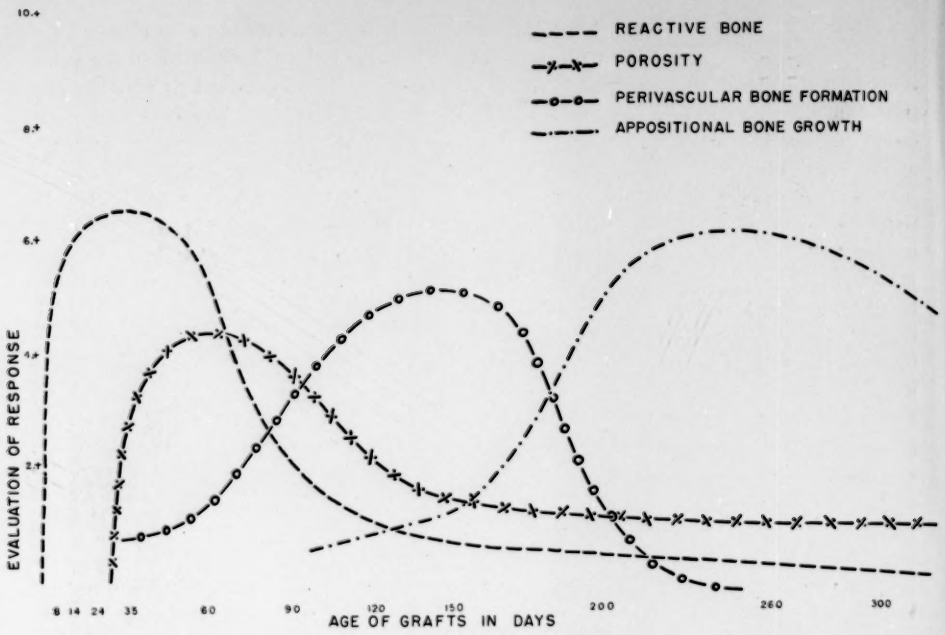
REACTIVE BONE
POROSITY
PERIVASCULAR BONE FORMATION
APPOSITIONAL BONE GROWTH
EVALUATION OF RESPONSE
8 14 24 35 60 90 120 150 200 260 300
AGE OF GRAFTS IN DAYS

CHART I

A graphic summary of the four phases of graft incorporation by the host. Plus units are used to denote the intensity of response which is numerically evaluated on the graph ordinate.

onstrated by profuse intramedullary and periosteal trabecular bone formation in which can be seen a considerable number of multinuclear giant cells. There was a notable intramedullary reaction in the host as early as at eight days (Figs. 1 and 2); however, it was most marked at fourteen days (Figs. 3 and 4). As early as the twenty-fourth day the reactive bone appeared to be maturing as the trabeculae thickened and the intramedullary spaces were noticeably widened. The intramedullary cavity was still filled with reactive bone (Fig. 5). This type of reactive bone formation seals the graft in a form of fixation to the host. The next phase is remodeling, which may be defined as the restoration of the anatomical continuity of the intramedullary cavity, of the periosteum, and the obliteration of the contact sites by mature bone (Fig. 6). Completed remodeling represents the terminal phase of reactive bone formation. Usually this reactive response was completed between ninety and 120 days.

2. *Revascularization:* This is the intense vascular phenomenon associated with porosity of the graft and accompanied by a very similar response in the host. It was consistently evident as early as the thirty-fifth day. Through mediation of mononuclear and multinuclear cellular de-ossification the original Haversian vascular channels are apparently enlarged to form a series of confluent sinusoids (Figs. 7 and 8). This vascular response follows the pre-existing channels throughout the graft as if it were a trellis. Revascularization of the graft and host and the resultant porosity was most marked at between sixty and ninety days (Fig. 7). It was still markedly evident at 120 days. After this period the vascular channels of both the host and the graft persisted in slightly increased number and size throughout the period of 260 days.

3. *Perivascular Bone Formation:* New mature-appearing bone was laid down concentrically around the vascular sinusoids. The lumen of these channels gradually decreased in size in direct proportion to the amount of new mature bone which was formed (Fig. 9). It was noted that the concentric lamellae which replaced the porosity resulted in the formation of uniform bone.

4. *Appositional Bone Substitution:* The new bone which was laid down in a form provided by the pattern of vascularization in some instances did not include all of the graft substance. Therefore, some irregular elements of the dead graft remained. It may be that these will be eliminated by appositional growth in the manner by which normal bone ordinarily sustains itself. This is not a dramatic tissue response but a slowly progressive one; this process has been designated as creeping substitution (Fig. 10).

The histological phases previously described are not clean-cut or sharply differentiated but blend one into another as demonstrated in Figure 11. The manner of graft incorporation did not appear to differ in any of the transplants. The notable differences were those of rate. Frozen homogenous grafts, particularly in the early stages, appeared to be incorporated more slowly than the freeze-dried bone. Apparently freeze-dried bone is incorporated by the host at a slightly slower rate although in a manner identical to fresh autogenous bone. Defects implanted with frozen homogenous grafts healed in an identical manner although probably at a slower rate than those grafted with freeze-dried homogenous bone. Except for these differences in rate, the healing of all defects in which grafts were used was roughly comparable to that of the bone defects in which no grafting was done. However, it was noted that in the untreated bone defect there was a preponderance of cartilage over bone after 142 days.

Of interest in this small series is the suggestion that in certain respects, that is, the rate of revascularization and early new-bone formation about the graft, freeze-dried bone is more rapidly transformed into new bone than is frozen bone. While the difference in rate is probably not clinically significant, it is significant enough to warrant further experimental explorations. The possibility that bone protein is changed by freezing or freeze-drying may partly explain the slight delay in incorporation, as compared to fresh autogenous bone; this is currently being investigated.

The results of these operative procedures seemed to justify clinical use. Accordingly six patients were treated with freeze-dried homogenous grafts at the United States Naval Hospital, Bethesda, Maryland. The end results will be reported at a later date. Early results in patients both roentgenographically and clinically, have supported experimental findings in the animal.

These results should form the basis for extensive investigations on the practicality of a large bone bank which would meet the needs of the majority of naval hospitals. The procurement and use of such grafts should be under the control of a central authority.

CONCLUSIONS

1. Freeze-dried homogenous bone grafts measuring 6 to 8 centimeters by 0.5 to 1.0 centimeter were grafted into the radii of dogs. It was found that they were incorporated in the same manner as fresh autogenous bone grafts but at a slightly slower rate. The freeze-dried bone was somewhat superior to frozen bone in regard to the rate of healing in the early phases.

2. Except for the previously mentioned variations in the rate of healing, all the grafts were incorporated in a manner roughly comparable to the healing of the bone defect of the same size in which grafts were not implanted.

3. The advantages of storage at room temperatures, the potentially increased storage periods, the ease of transportation, and initial clinical success suggest that freeze-dried homogenous bone is suitable for use in bone banks.

NOTE: Photomicrographs are produced by courtesy of *Armed Forces Institute of Pathology* and *Photographic Department, Naval Medical School, Bethesda, Maryland.*

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DISCUSSION

DR. PAUL R. LIPSCOMB, ROCHESTER, MINNESOTA: Codman made the statement, "Give me something different for there is a chance of its being better". The authors of this paper have given us a different method of preserving bone and, although it is admittedly better for the long-term preservation of the proteins, enzymes, and salts of stored bone, the question arises, is this method better from a practical and economical standpoint? The authors could detect no appreciable difference in the results when bone preserved by freeze-drying was used from those when bone frozen for an average of twenty-nine days was used.

The authors stated that denaturation of proteins is detrimental to acceptance of any graft by the host, for it evokes a foreign-body response. This statement to me seems logical, and yet Reynolds and Oliver stated that bone preserved in merthiolate is just as satisfactory as bone preserved by freezing. Merthiolate and most other antiseptics derive their power from the fact that they are protein coagulants. At the Mayo Clinic we have noted no ill effects which could be attributed to protein denaturation when we used bone preserved by freezing alone, although we have been hesitant to use bone which has been preserved for more than three to six months. It is obvious that, if protein denaturation does not affect the fate of the transplant, those of us who are going to the trouble and expense of minimizing protein denaturation by using frozen bone are doing so needlessly. Likewise, if this is the case, and I doubt it, the complicated and expensive process of freeze-drying whereby the denaturation of protein is absolutely stopped would not be justified. Although the freeze-drying or lyophilization process of the preservation of bone is from a theoretical standpoint the best method yet developed for preserving bone, one wonders whether, from a practical and economical standpoint, the method is sufficiently better to justify its use in civilian practice in preference to the other two methods which have been advocated. In military practice, when the procurement of the bone is under a central authority and the bank would necessarily be large, this method of preservation of bone would be ideal provided that such bone is definitely superior to that preserved by antiseptics. Likewise, should the Red Cross or the pharmaceutical companies ever dispense homogenous bone by methods of distribution similar to those now being used for plasma, this process would probably be feasible.

Those who believe that some osteoblasts actually live when transplanted in fresh autogenous grafts argue that autogenous transplants are superior to homogenous transplants for this reason. This argument may be settled by a comparison of lyophilized autogenous transplants with fresh autogenous transplants. In the first instance, the salts, proteins, and enzymes and presumably the tissue specificity would be unchanged, but all living cells would be destroyed, whereas in the fresh autogenous graft, living cells would be retained. It may be that the freeze-drying process, since it destroys the cells of bone but, as far as we know, does not alter the chemistry *in vitro*, will give us another valuable tool for the study of osteogenesis. I would like to ask the authors if they have made any observations suggestive of this.

The authors are to be congratulated for presenting to us another method of preserving bone and for their scientific and long-term analysis of the efficacy of bone so preserved.

DR. JAMES B. WEAVER, KANSAS CITY, KANSAS: I feel that Captain Kreuz and his associates have done a well thought-out, well-planned, and well-executed piece of research work.

There are two things which I would like to have clarified if Lieutenant Hyatt will do so. No mention has been made as to the effect on the sterility of these grafts by freeze-drying. Does freeze-drying kill bacteria or not? I assume that it does not.

The statement was made that the end product of this process is porous and crumbly. We have all had the experience of relying upon our graft for a certain amount of internal fixation, yet frequently at the site of stress and strain we get absorption of the graft and non-union. If freeze-dried bone is more friable, then what are we to expect if we use this bone for internal fixation?

LIEUTENANT HYATT (closing): In reference to Dr. Lipscomb's comments, we feel that the theoretical protein difference is notoriously difficult to evaluate in experimental animals, and will probably best be determined by objective observations over a long period of time. We do not recommend freeze-drying as a method for general use. It will be a closely controlled clinical research project, and in five to seven years, we may have an answer.

With reference to protein products in relation to their denaturation by methods of preservation, we are now doing some work which is an evaluation utilizing enzyme digestion of the denatured protein products. In this manner the degree of denaturation of bone protein resulting from a method of preservation may be numerically evaluated.

(*Continued on page 888*)

CLINICAL EVALUATION OF THE MERTHIOLATE BONE BANK AND HOMOGENOUS BONE GRAFTS

BY FRED C. REYNOLDS, M.D., DAVID R. OLIVER, M.D., AND ROBERT RAMSEY, M.D., ST. LOUIS, MISSOURI

From the Department of Surgery, Washington University School of Medicine, St. Louis

In a previous publication [1] the clinical use of homogenous bone grafts from the merthiolate bone bank was discussed in the form of a preliminary report and the technique of setting up and maintaining the bank was described. Sufficient time has now elapsed for a critical analysis of our original views both on the method of preserving bone and on the use of preserved homogenous bone grafts.

As a result of our observations on the fate of homogenous bone grafts in the experimental animal [2] and after a brief clinical trial, we concluded that:

"1. The process of fixation and replacement of both autogenous and known dead homogenous bone grafts is accomplished in an identical manner, experimentally and clinically.

"2. The merthiolate bone bank offers a simple, inexpensive, and aseptic method of preserving homogenous bone.

"3. Merthiolate-preserved bone is well tolerated in the tissues, and early results obtained with grafts from the merthiolate bone bank compare favorably with autogenous grafts under similar circumstances.

"4. No sensitivity to merthiolate has been encountered in any case.

"5. Experimentally and clinically, the early phases of healing are somewhat slower with homogenous grafts than with autogenous grafts. Therefore, it is important that immobilization be continued over a longer period of time."

A more extensive clinical experience calls for certain revisions of these opinions, which this article will attempt to set forth.

Concerning the bone bank, our source of bone remains the same,—that is, ribs removed by the Chest Service during thoracotomies and thoracoplasties, and bone from clean amputations and selected autopsies. Preparation of bone obtained from these various sources is still carried out as a clean surgical procedure in the operating room. This consists in removing as much soft tissue as possible and cutting the bone into convenient shapes. The bone is then placed in a sterile jar and covered with a solution of 1 to 1000 aqueous merthiolate. The jar is sealed and stored in an ordinary ice box adjacent to the operating room. Refrigeration is not necessary and, if an ice box is not available, a cabinet will do as well.

At first the solutions were changed every two weeks and cultures were made at each changing until three negative cultures had been obtained; then the solution was changed to 1 to 5000 aqueous merthiolate. Thereafter this proportion was retained, but the solution was still changed at two-week intervals and cultures were made at that time. These frequent changes became quite a task and gradually the interval between changes lapsed to four or six weeks. With the bone in a 1 to 5000 solution which had not been changed for six weeks, a positive culture was obtained on two occasions. For this reason the solution is no longer diluted after the initial period of two weeks, but is continued at 1 to 1000 and changed every two weeks. So far there has not been a positive culture from bone preserved in this concentration. All bone which is to be used is briefly washed in sterile saline solution after it has been removed from the bank. The increased concentration of the solution has made no detectable difference in tissue reaction or the fate of the graft.

One of the criticisms of the merthiolate bone bank has been that frequent changes

TABLE I

SUMMARY AND END-RESULTS OF 212 OPERATIONS

	No.	Total No.
Operations		
Followed for one year or more (121 patients)	129	
Operations done within a year	39	
Lost to follow-up	22	
Performed at other hospitals	19	
Deaths (not due to operation)	3	
Total		212
End-Results		
Solid	90	
Failure	39	
Total followed for one year or more		129
Postoperative Infection		
In wounds which were clean at operation	6	
In wounds which were draining at or just preceding operation	5	
Absorption of graft without infection	12	

increase the chances of contamination and lead to infection of the bank. The authors' experience has been just the opposite, in that frequent changes keep the bone in better condition. There is less chance of infection of the bone with fresh solution, as undoubtedly a considerable amount of the chemical is precipitated with coagulation of the superficial protein elements of bone. Also, with each change additional soft tissue is removed and the bone and solution have a cleaner appearance.

A jar containing tibial bone in a 1 to 5000 solution of merthiolate was shown in the writers' exhibit at the 1949 meeting of The American Academy of Orthopaedic Surgeons. This bone was handled by a good many people and no attempt was made to keep it sterile. At the end of the meeting, cultures were made from this bone and a luxuriant growth of organisms was obtained. Without any other treatment, the bone was then placed in a sterile container and covered with a 1 to 1000 solution of aqueous merthiolate. This solution was changed at two-week intervals; cultures obtained at each change were negative. After three negative cultures this bone was added to the regular stock. In the course of time all of this bone was used clinically, and we have been unable to trace any unfavorable reaction. The writers are inclined to consider this a fair test of the ability of merthiolate to sterilize contaminated bone and to preserve it in a sterile state.

So far as the merthiolate bone bank is concerned, it can be definitely stated that it affords a satisfactory method of preserving bone. In the 212 operations in which bone from the bank has been used, there has not been a single recognized case of allergic reaction, nor has there been any evidence of excess tissue reaction.

In the 129 operations covered in this report, postoperative wound infection occurred eleven times (Table I). Five of these wounds either were draining at the time of operation or had but recently stopped draining. Six instances of postoperative infection in clean cases is a higher incidence than one would expect from autogenous bone grafts or from any other orthopaedic procedure. In each instance, cultures of the bank had been repeatedly negative and cultures made after the reported infection were still negative. This might lead to the conclusion that the organisms were deep-seated and would not be obtained on culture; however, cultures are made from a piece of the bone as well as from the solution.

An experimental comparison [2] of the fate of autogenous bone grafts and various types of homogenous bone grafts led to the following conclusions:

"1. There is no evidence from these experiments that any of the bone elements of an autogenous transplant live or retain osteogenetic powers.

"2. The authors have demonstrated that, with the inlay type of graft, the fixation and replacement of the graft was totally a function of the host tissue.

"3. The fixation and replacement of both autogenous and homogenous bone grafts was accomplished in an identical fashion by appositional growth of the host bone. So-called creeping substitution was but a localized phase in the process of appositional bone growth.

"4. Autogenous bone grafts were superior to homogenous bone grafts experimentally only in that the early phase of healing was slightly more rapid and uniform. However, this was not due to viability and regrowth of autogenous grafts; rather it probably represented less host reaction and tissue specificity, which are factors not understood at present.

"5. At the end of ten weeks, no microscopic difference could be seen between the autogenous and homogenous grafts; practically complete replacement was present in both.

"6. Merthiolate-preserved bone and frozen homogenous bone were indistinguishable experimentally. Boiled homogenous bone, however, proceeded to union much more slowly.

"7. The clinical use of homogenous bone graft is justifiable."

TABLE II

BONE-BANK GRAFTS FOR SPINE FUSIONS

No. of Operations	Solid	Failures	Infection Following Spine Fusion	Absorption of Graft	Symptoms			
					Failures		Solid	
					Pain	No Pain	Pain	No Pain
50	33	17	5	7	12	5	12	21

Furthermore, sections of grafts obtained at second operations demonstrated comparable microscopic pictures. From these experimental and clinical observations, we felt certain that the most important element in early union and replacement of the various types of bone grafts was the reaction of the host tissue, that should some or all of the cells lining the Haversian system, the endosteum, and the cambium layer of the periosteum survive, they could not play a very important role in determining the fate of the graft. So far, it has not been possible to devise an experiment to prove conclusively whether or not some elements of an autogenous transplant live and are capable of aiding in replacement of the graft, nor do we know of such an experiment elsewhere. Hatcher has demonstrated to us evidence of proliferation of the cells lining the Haversian canals with early creeping substitution in two autogenous grafts at the end of seven and twelve days, respectively, before complete organization of the hematoma. This is positive evidence to support the theory that these cells do survive under favorable circumstances and are capable of instigating the process of fixation and replacement of the grafts. There is no question that most of the mass of any autogenous bone graft dies and must be replaced. There is also no question in our minds that all elements of preserved bone are dead and must be replaced.

In a total of 212 operations in which bone from the bone bank was used, 121 patients with 129 such operations were followed for one year or more. Some of the cases listed in the authors' previous report are not included in the series presented here, as these patients did not return for follow-up examination. Nineteen of the 212 operations were done at other hospitals, the bone being provided from our bank. Results in these nineteen cases are not included because sufficient data to determine the end results could not be obtained. Three patients died before the end results could be determined, although there were no operative deaths. Thirty-nine operations were performed during the past year and were therefore not included. Twenty-two patients could not be reached for follow-up clinical or roentgenographic examination. Many of these will return and may later be included; however, for this report they must be counted as lost.

FIG. 1-A

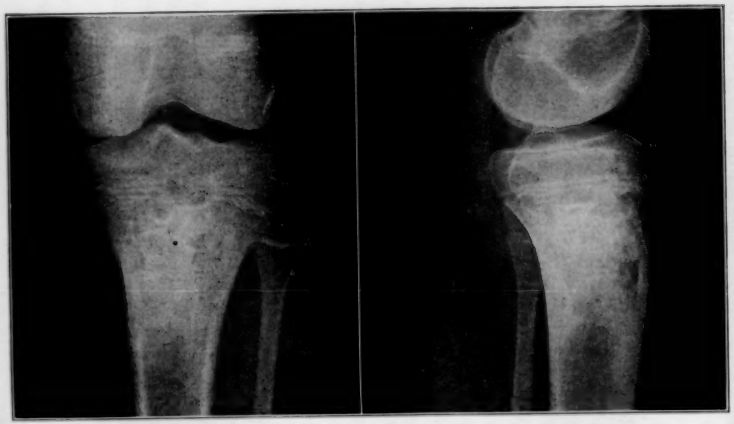

FIG. 1-B

FIG. 1-C

Fig. 1-A: Preoperative roentgenogram.

Fig. 1-B: Seven months following sequestrectomy. Obliteration of defect with chipped ribs and wound closure. The wound remained healed.

Fig. 1-C: Thirty months after operation. Patient has remained symptom-free.

TABLE III

RESULTS IN FIFTY-FOUR PATIENTS

Types of Operation	No. of Cases	Solid	Failure	Absorption of Graft	Infection
Arthrodesis	17	16	1	0	0
Fresh fractures	10	9	1	0	0
Defect after saucerization for osteomyelitis	7	6	1	0	1
Defect after removal of benign tumor	9	6	3	1 malignant tumor * 1 cyst †	1
Aseptic necrosis, head of femur	4	4	0	0	0
Shelf operation for congenitally dislocated hip	2	0	2	2	0
Legg-Perthes' disease	1	1	0	0	0
Osteotomy defects	4	4	0	0	0
Total	54	46	8	2	2

* A giant-cell tumor became malignant.
† Continued activity of simple cyst.

Of the 129 operations, fifty were spine fusions (Table II). In each case a modified Hibbs fusion reinforced with bank bone was used. Cortical and cancellous bone from the tibia, split ribs, and iliac bone were all used. Of these, split ribs were used in forty-one operations, with twenty-seven becoming solid and fourteen failing. Cortical tibial bone was used in two cases; one failed. Iliac bone alone and combined iliac and rib grafts were used once, each with success. Combinations of ribs and tibial bone were used in five cases, with three failures. The fifty spine fusions were done for a variety of conditions,—namely, tuberculosis, tumors, spondylolisthesis, unexplained low-back pain, and recurrent disc syndromes, the largest groups being the last two. The postoperative treatment varied. The majority of patients were in a body cast for three months, followed by a Taylor brace for three to four months. However, a few remained at bed rest for three to four weeks, after which a corset was used; these patients seemed to do as well as those in plaster fixation.

In thirty-three cases bone grafts resulted in solid spine fusion and in seventeen failed. The cause of failure in five cases might be attributed to postoperative wound infections. In spite of removal of the graft, two of these became solid and symptom-free later. In six cases in which fusion failed, the graft became incorporated, but a definite pseudarthrosis developed. In seven cases, the grafts were gradually absorbed, with little or no roentgenographic evidence of their presence after one year. Five of the seventeen cases counted as failures because of lack of roentgenographic evidence of fusion were symptom-free. In twelve of the cases considered definitely solid by roentgenogram, pain was still present. It is frequently difficult to be sure from x-ray evidence alone whether or not a spine fusion is solid; more than one patient whose roentgenograms appeared to show a pseudarthrosis was found at reoperation to have solid fusion. It is safe to say that some of the cases which appear solid and are here so classed would not be found solid upon exploration, while perhaps some of those classed as failures would be found solid. Lack of evidence of fusion in 36 per cent. of the cases seems a high proportion of failure.

Certainly the incidence of wound infection in this series is higher than that in spine fusions in which autogenous grafts were used. We have not observed absorption of autogenous grafts in a clean wound which would compare with the absorption that occurred in bank grafts.

Bank bone was used to obliterate cavities remaining after local removal of benign bone tumors in nine cases (Table III). In six of these the graft became solidly fused and there were three failures. Failure was due to infection in one case and in another to

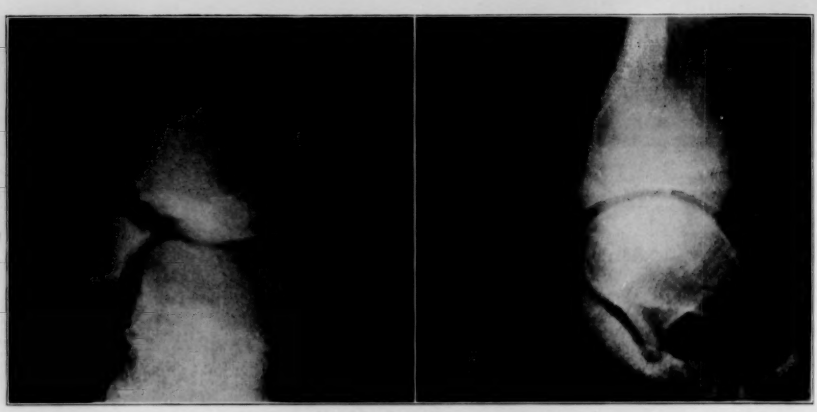

FIG. 2-A
Non-union of tibial malleolus of about one year's duration.

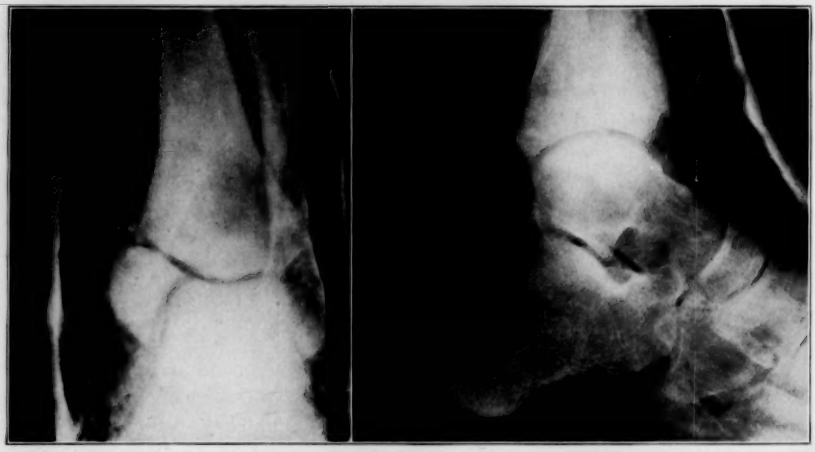

FIG. 2-B
Roentgenogram taken shortly after operation.

malignant degeneration which occurred with beginning absorption of the graft. Examination of the specimen following amputation revealed solid incorporation of some of the grafts, while others were surrounded with scar tissue and appeared about the same as when removed from the bank. In the third case, continued activity of a solitary bone cyst resulted in absorption.

Chipped ribs or rib strips were used in most cases. These show slow consolidation but satisfactory progression of union. Iliac bone is more suitable in most circumstances. Cancellous bone with a large fat content such as tibial condylar bone does not appear to be as suitable as either of these.

Defects remaining after saucerization for osteomyelitis were obliterated in seven cases with healing of the wound and bone cavity in six and continuation of infection with loss of the graft in one. This failure was due to slough of the skin flap. In four cases a single-stage operation was done,—that is, sequestrectomy, bone graft to obliterate the defect, and closure of the wound. Three of these remained healed (Figs. 1-A to 1-C); one failed as described above. The others were packed open at the time of sequestrectomy and secondary

TABLE IV
BONE GRAFTS FOR NON-UNION
(TWENTY-FIVE CASES)

Site of Non-union	Solid	Failure	Infection	Absorption of Graft
Humerus	1	1		
Forearm				
Radius	1	0		1
Ulna	4	4	2	1
Femoral Shaft	0	2		
Femoral Neck	0	5		
Tibial Shaft	1	3	2	
Tibial Malleolus	3	0		
Total	10	15	4	2

closure of the wound five to seven days later, the cavity being obliterated with bank bone at that time. Two of these drained for several weeks but healed and have remained healed without loss of graft or further surgical procedures.

Homogenous grafts were used in the treatment of twenty-five cases of non-union of fractures (Table IV). In fifteen of these, solid union did not result. There were four infections, and in two clean cases apparent absorption of the graft occurred. Most major non-unions failed, only one humerus and one tibia succeeding. The humerus did not become solid for over twelve months and the tibia for more than six months. An opportunity to compare homogenous and autogenous grafts in the same patient occurred in a case of bilateral non-union of the tibial shaft. The left leg was treated with an autogenous iliac graft, the right with a tibial cortical graft from the bank. The autogenous graft became solid in three months and the bank graft, which had appeared to be progressing satisfactorily, broke at five months and resulted in failure of union. On the other hand, a non-union of the ulna that had failed with autogenous bone grafts healed following a bank graft.

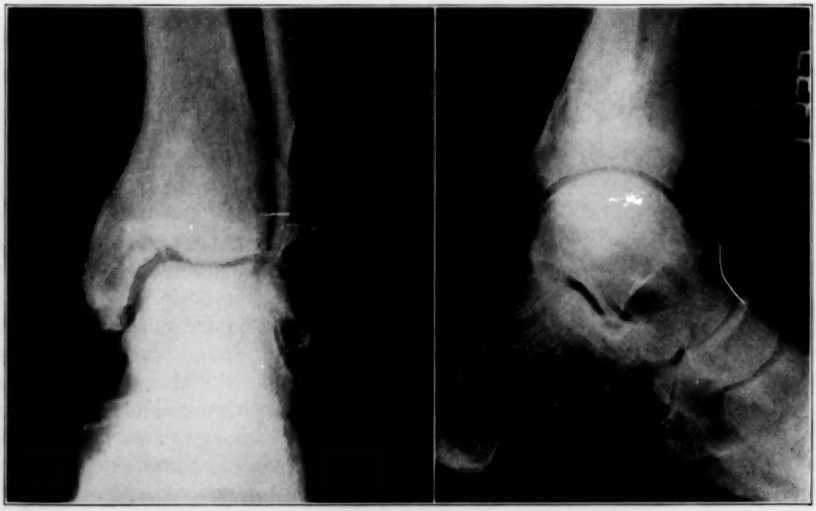

FIG. 2-C
Eighteen months after operation.

FIG. 3-A
Original roentgenograms showing tuberculosis of the hip.

FIG. 3-B
Following Brittain type of arthrodesis with an autogenous tibial graft.

FIG. 3-C
Six months after Trumble-type arthrodesis with a bone-bank tibial graft. It appears that the graft has fractured.

The authors are now reluctant to use bank bone in any cases of major non-union if there is a possibility of using autogenous bone. We do not hesitate to use homogenous peg or inlay grafts in cases of minor non-union, as these have uniformly done well (Fig. 2-A). The four infections listed are in two cases which had been infected previous to the operation and might have had a "flare-up" with any type of graft.

Bone from the bank was used to augment the procedure of arthrodesis of various joints in seventeen cases, with sixteen successes. One of these, a case of tuberculosis of the hip, had failed with an autogenous graft (Figs. 3-A to 3-E), probably because the graft was placed into diseased tissue at the lower acetabulum. Reoperation and a Trumble-type procedure with tibial graft from the bank resulted in solid fusion, even though it appears that the graft broke and then united. Many of these cases would have become solidly united without the presence of extra bone, so that it is difficult to say just how much the bank bone helped in the healing process; at least it did not hinder union and did provide a form of internal splint in many cases.

Bank bone was used in the treatment of fresh fractures in nine cases where it appeared that extra bone would be useful or would provide an internal splint, particularly in

FIG. 3-D

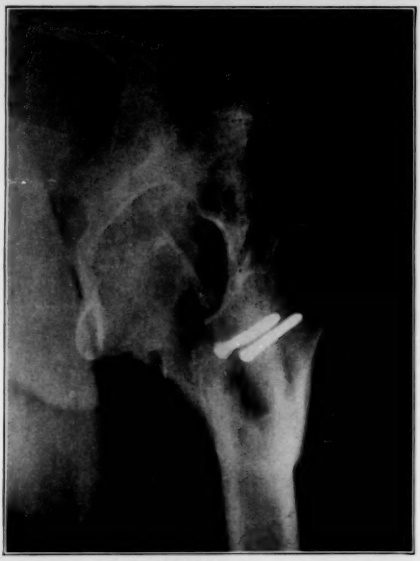

FIG. 3-E

Anteroposterior and lateral views eighteen months after operation show solid fusion of the grafts.

depressed fractures of the tibial condyle and the os calcis. Iliac bone was used in these cases, with rapid incorporation of the graft and solid union (Figs. 4-A to 4-C). Failure of union occurred in one case. This was a fresh fracture of the neck of the femur treated with a Smith-Petersen nail and tibial graft from the bank. Bank bone was also used in four cases to fill the defect of an osteotomy with union in each case. Here again union would probably have occurred without the graft. Another use of bank-bone grafts was in four cases of aseptic necrosis of the femoral head, in which drill holes were made into the head and slivers of tibia or rib from the bank placed in these holes, after the method of Phemister. The grafts all became incorporated rapidly and it appears that replacement of the head was speeded up and further collapse prevented. There was also relief of pain in varying degrees.

Tibial pegs were used in two cases of congenital dislocation of the hip to form a shelf, but both promptly melted away and redislocation of the hip followed.

The Steele operation was done in one case of Legg-Perthes' disease of long standing. The cavity was curetted and filled with tibial chips. Consolidation was rapid, so that full weight-bearing was allowed at six months. This hip has remained good.

In spite of the fact that in animal experiments (with dogs) there is very little difference in the behavior of autogenous bone grafts and preserved bone grafts, either frozen or merthiolate, clinical experience reveals a rather marked difference. Our experimental work was all done with inlay grafts which were small and which were placed into normal bone, rigid immobilization being supplied by the host bone which remained intact. It seems reasonable to believe that, could the problem be duplicated in human patients, the comparative end results would be the same. The duration of the process of replacement of the graft is expected to vary with each individual. However, it appears that the fate of a homogenous bone graft in clinical cases is unpredictable. In some cases the graft is rapidly incorporated and becomes solid, as determined by roentgenogram, in a short period of time. These cases parallel the response to autogenous bone grafts. In other cases the bone appears to lie dormant without much roentgenographic evidence of change for a long period of time. Reoperation in these cases has revealed the bone completely surrounded by fibrous tissue, appearing just as it did when it was grafted. Many times there is a combination

FIG. 4-A

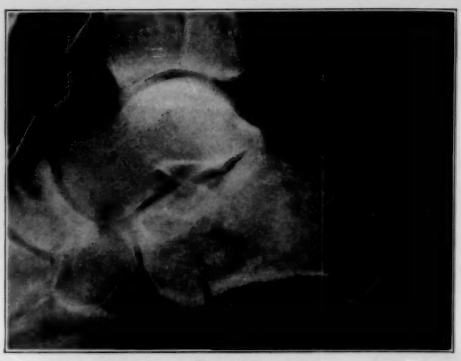

FIG. 4-B

Fig. 4-A: Depressed fracture of the calcaneus. Fig. 4-B: Roentgenogram made after the depressed subastragular floor had been elevated and the defect had been filled with iliac graft from the bank.

FIG. 4-C

Roentgenogram made four months after graft, showing solid union. A check-up examination two years later found this man doing his regular work, which requires considerable walking and climbing of ladders.

of these two features, some portions of the graft becoming fixed to the host bone and other pieces remaining unchanged. Again, many cases show evidence of complete or almost complete absorption of the grafts. So far as is known, there is no way of predicting which of these trains of events will occur, except that results in this series show that the most satisfactory homogenous grafts were made under conditions where the bone was used as an inlay or as an intramedullary peg.

The use of preserved bone for the obliteration of cavities reveals slow incorporation of the graft but eventual healing, except in cases of malignant degeneration, continued activity of a solitary cyst, or in the presence of infection. Preserved grafts in minor non-unions, such as those in the tibial malleolus or olecranon, have done well. Preserved homogenous bone grafts in major non-unions have almost always failed to result in union of the fracture (Table III). In a like manner, combining one or more bank grafts with a Smith-Petersen nail for non-union of the femoral neck has resulted in failure.

The most varied reaction is found in spine fusions. Here there were cases of large masses of solid bone on one hand and complete or almost complete disappearance of the grafts on the other. All types of bone gave better results when only small or moderate quantities were used. Reoperation for pseudarthrosis after large quantities of either type of bone were grafted revealed a considerable portion of the bone walled off and surrounded by scar. It appeared that the great mass of bone could not be incorporated by the host before connective tissue created a barrier.

SUMMARY

The authors remain convinced that the process of fixation and replacement is accomplished in a similar manner in autogenous and homogenous bone grafts, but we are not at all sure that the differences in time of union and the number of failures can be explained entirely on the basis of tissue specificity. There is reason to believe that some of the cells of an autogenous graft are capable of survival and of instigating this process and thus accelerating it when host capillaries reach the graft. This could account both for the more rapid union of the autogenous graft as compared with homogenous graft and for the greater number of successes with autogenous grafts. Merthiolate-preserved bone does not compare favorably with autogenous bone grafts in that the process of fixation and replacement is definitely retarded, requiring prolonged protection with a higher percentage of failures (30.24 per cent. in this series).

The merthiolate bone bank is a very satisfactory method of preserving bone. We have no evidence of sensitivity to the merthiolate or excess tissue reaction to merthiolate-preserved bone. The method is certainly easier and more economical of bone than the frozen bone back.

A homogenous bone graft which is adequately placed in a good bed and protected for a sufficiently long time may be expected to unite. Many of the failures listed above should not be ascribed to the bone bank or to homogenous bone grafts but to poor surgery. Still others can be attributed to the injudicious use of bone grafts; in these cases failure would probably have occurred irrespective of whether a homogenous or an autogenous graft was used. However, we have modified our original expectations of preserved homogenous bone graft and now feel that these grafts should be considered as useful aids in orthopaedic surgery rather than as universal substitutes for autogenous bone. Obliteration of cavities in bone created by sequestrectomy and saucerization for osteomyelitis, or local excision of benign tumors by homogenous bone from the bank, has given good results. Where the defect is large, bank bone is preferable to autogenous bone because of the great amount required. Homogenous peg or inlay grafts have proved satisfactory in the treatment of minor non-unions. Likewise, bank bone has been very useful for internal splinting in arthrodesis and for treating certain fresh fractures. However, homogenous bone grafts should never be used in the treatment of major non-unions if there is any possibility of using an autogenous graft. It is our feeling that the use of bank bone should be reserved for those circumstances in which it is not feasible or advisable to use autogenous bone. These are:

1. When the available supply of autogenous bone does not fulfill the particular requirements;

2. When the taking of an autogenous bone graft will materially increase the hazard of the operative procedure;

3. In any condition where there is a chance that the graft will be lost because of infection;

4. During the course of an operation when it is decided that a bone graft would be useful and when no previous plans for taking a graft had been made;

5. In those cases where the bank bone is used as an internal splint when the condition would not justify the taking of an autogenous graft.

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BRACHIAL PLEXUS BLOCK ANALGESIA WITH XYLOCAINE *

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Until recently, brachial plexus block analgesia for the upper extremities was rarely employed in the Scandinavian countries, but it has received a fresh impetus from the increasing attention now being paid to hand surgery, due in great measure to the outstanding work in that field done in the United States during the past few decades.

For many years there have been reports from various sources concerning this block analgesia [8, 11, 13, 15]. Most of these reports cover only a small number of cases, but recently Bonica, Moore, and Orlov published results of about 1,500 brachial plexus blocks performed under several different analgesics. The results reported are generally favorable, and because of the obvious advantages of this type of analgesic it may be asked why it is not used more frequently.

Complications such as pneumothorax, mediastinal emphysema[6], temporary paralysis of the phrenic nerve [17], and drug reactions are mentioned in the literature. (Two fatal cases which were reported by Paus in 1947 might have been cases of air embolism.) Such complications are few. The authors believe that these complications and the fear of unsatisfactory analgesia must be among the reasons why many anaesthesiologists and surgeons are reluctant to use brachial plexus blocks with procaine.

There is, however, a new type of local anaesthetic, xylocaine, which may eliminate some of the disadvantages of brachial plexus block as administered hitherto. The following report concerns the use of this anaesthetic in brachial plexus blocks.

Xylocaine is chiefly a product of discoveries by the Swedish chemists Löfgren and Lundqvist. It consists of the hydrochloride of diethylaminoacet -2.6- xylidide. It is reported to possess great chemical stability, so that it can be boiled for hours and still remain stable for an indefinite period. A special method makes it possible to produce stable solutions of xylocaine and epinephrine which will retain their properties unchanged for years. The toxicity is said to be similar to that of procaine, and the analgesic potency two to four times as high. Therefore, the ratio between the analgesic potency and toxicity, the so-called safety ratio, should be two to four times as high as for procaine in infiltration and block analgesia.

Since the first clinical investigations by Gordh and by Bremer in 1949 there have already been other reports concerning xylocaine. Dabbs and Southworth at the United States Marine Hospital, Baltimore, and Hanson and Hingson at Johns Hopkins University have had gratifying results, the two latter especially in tests with continuous caudal analgesia. Gruber finds the drug much more active on sensory nerve fibers than on motor fibers.

As far as we know, the only reports so far on the use of xylocaine in brachial plexus block are those on twenty-six cases mentioned in a summarizing report by Gordh, and those by Ciocatto, Dabbs and Southworth, and Taccani. The object of this paper is to compare xylocaine with procaine in brachial plexus blocks. During an eighteen-month period, 300 consecutive brachial plexus blocks were carefully recorded. Of these, 185 were done with procaine and 115 with xylocaine. The authors have had no experience with other analgesics. During the period mentioned all patients without complaints were followed for at least three weeks, most of them much longer. All the patients with complaints were examined by the authors personally and were followed for months. The authors' experience in this Hospital now includes about 700 brachial plexus blocks; xylocaine was used in

* Read at the Fifth Annual Meeting of the American Society for Surgery of the Hand, New York, N. Y., February 10, 1950.

TABLE I

RESULTS IN BRACHIAL PLEXUS BLOCKS WITH PROCAINE AND WITH XYLOCAINE

		Proximal Localization of Lesion Operated Upon					Total
		Brachium	Region of Elbow	Forearm	Carpal Region	Hand	
Procaine — 185 cases	No. of injections	0	14	16	32	123	185
	Discomfort — no other anaesthesia necessary		2	1	3	11	17
	Additional anaesthesia		3	6	2	10	21 *
Xylocaine — 115 cases	No. of injections	3	18	10	11	73	115
	Discomfort — no other anaesthesia necessary	0	1	0	0	0	1
	Additional anaesthesia	0	0	0	0	4	4 **

* In nine of these, additional anaesthesia was necessary because of the long duration of the operation.
** In all four cases, additional anaesthesia had to be administered because of faulty technique.

about 165 of these cases. Training in the technique of effecting brachial plexus blocks is very important for good results. One of the writers (Moberg) has a total experience of about 500 blocks; with very few exceptions, his patients were placed in the sitting position during the injection. The other (Dhunér) prefers to make the injections with the patient in a supine position. Few of the blocks in this series were performed by other, less experienced surgeons.

Nothing in the 400 cases not reported indicates any difference from the cases discussed in this series, and no really serious after-effects have been observed so far, but of course we know that, as the number of cases increases, we cannot expect to escape these completely.

The extent to which the writers use this analgesic in surgery of the hand may be indicated by the fact that one of them (Moberg) operated on fifty-nine cases of Dupuytren's contracture, using brachial plexus block in all cases with xylocaine in about one third and with procaine in the other two thirds. In only two cases was general anaesthesia added, and only a few additional ulnar blocks were necessary. In every case, of course, the pneumatic tourniquet was used for all dissection during the operation. The average amount of fibrous tissue removed was 6.1 grams, and in a few cases the maximum was 14 to 16 grams.

A premedication, usually consisting of 10 to 15 milligrams of morphine and 0.4 to 0.6 milligrams of scopolamine, is administered for the brachial plexus blocks with xylocaine. The xylocaine dosage was 10 to 15 cubic centimeters of a 2 per cent. solution containing epinephrine 1 to 80,000, the procaine dosage 20 to 35 cubic centimeters of a 2 per cent. solution containing epinephrine 1 to 200,000. The supraclavicular approach with one needle was used. In every case only a single dose was injected. So far, the block analgesia has been used four times on one patient, three times on another, and twice on twenty-four patients. Injection performed on a human brachial nerve plexus obtained by autopsy shows that a water-soluble contrast fluid will spread along the nerves from one cord to another (Fig. 1). In a living nerve this seems to occur to a still greater extent, as has been shown by Dhunér. This may be the explanation of why it is possible to obtain satisfactory analgesia without attempting to locate more than one of the three separate cords for injection.

Table I lists the sites where surgery was performed and compares the results from xylocaine and procaine respectively.

The considerably greater duration of the analgesia with xylocaine is obvious from

TABLE II

COMPLICATIONS DURING OPERATION

	Procaine (185 cases)	Xylocaine (115 cases)
Marked drug reaction	1	1
Pneumothorax (partial)	1	1
Nausea	5	0
Fainting (injection not completed)	1	1 *

* Only 2 cubic centimeters was injected, but this was sufficient for one-half hour of good analgesia.

the fact that in nine cases of primarily good analgesia with procaine, the prolonged operation necessitated an additional anaesthetic, while this was not necessary with xylocaine. In four cases where the latter was used, the operation could be extended to between three and three and a half hours without additional anaesthetic, and in one case to four hours and fifty minutes. Xylocaine is believed to take effect more rapidly than procaine, but, as this is of minor importance, it is not indicated in the table.

The complications occurring during anaesthesia are shown in Table II.

Two postanalgetic complications occurring in this series should also be noted. These were two cases of possible nerve lesions in the group given procaine, while none of those given xylocaine showed this after-effect. The first was a motorcycle racer who suffered lacerations of his hand when he was hurled forward in an accident. A check-up examination nine months later revealed obvious atrophy of the supraspinatus and infraspinatus, and very slight reduction in the power of some of the intrinsic hand muscles. The plexus lesion had not been diagnosed earlier. It may have been due either to the plexus analgesia

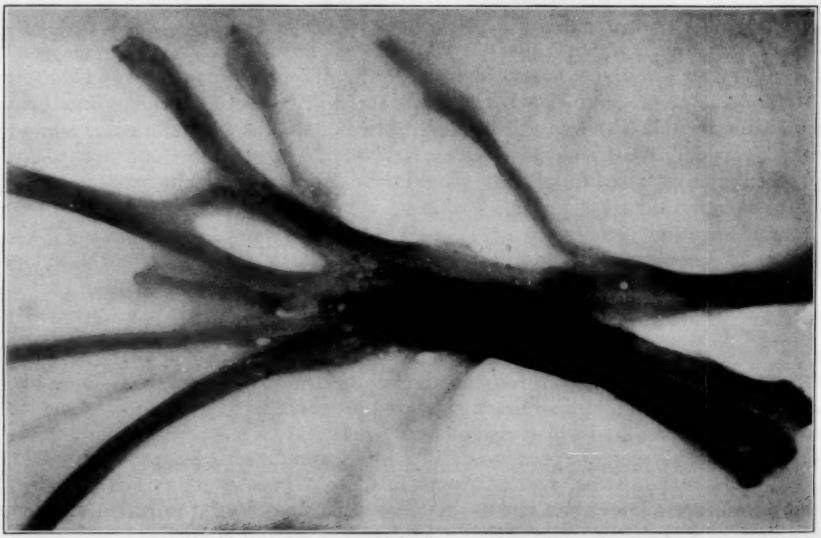

FIG. 1

A water-soluble contrast fluid injected into the brachial plexus will spread along the nerves and from one cord to another.

or to the accident. In the second patient a facial-nerve paralysis developed five days after anaesthesia and lasted for three weeks.

The second complication noted was radiating paraesthesia, which occurred in ten of the procaine cases and in seven of the xylocaine group. This was present for less than three weeks in seven of the procaine group and in three of the xylocaine group and for more than three weeks in three of the procaine and four of the xylocaine group.

These complaints and complications were revealed at the follow-up examination, and no attempt will be made here to determine their real cause. There were, without doubt, a few cases where paraesthesia of two to three months' duration was due to the plexus block; in the writers' opinion, this was caused by small intraneural hemotomata. No difference was found in this respect between xylocaine and procaine.

The effect of the higher concentration of the epinephrine used with xylocaine was checked in a small number of cases where, instead of xylocaine, 15 cubic centimeters of procaine was used with the same concentration of epinephrine 1 to 80,000. The onset of analgesia here was sooner than with epinephrine 1 to 200,000. However, the same enduring effect as that of xylocaine was never obtained.

This limited experience seems to show:

1. That brachial plexus block is an effective method for obtaining good analgesia in many cases of hand surgery;
2. That the xylocaine dosage can be kept down to about half that of procaine, with still better analgesia and longer duration;
3. That xylocaine takes effect more rapidly than procaine;
4. That it results in no more complications than procaine, and perhaps in fewer.

Xylocaine thus seems to have increased the field of usefulness for brachial plexus blocks in hand surgery.

Without any doubt, however, there are some technical data in administering the brachial plexus block which are of great importance for the results as well as for avoiding complications. The nerve trunks of the plexus must be stretched properly by depressing the shoulder and moving the head laterally to the other side. The needle must be fine and — this is important — very short. As the plexus cords are rarely located deeper than one inch below the skin surface, a longer needle is not desirable and may even be unsafe. With a short needle, and with the syringe attached throughout the operation, the risks of air embolism, pneumothorax, or mediastinal emphysema due to suction of the air through the needle into the veins and the pleura are minimized. The plexus nerves must be properly located by means of needle paraesthesia before the injection is made. When attempts were made to give the injection before the patient had experienced a shooting pain down the arm, analgesia was generally poor.

One of the most urgent surgical problems is to improve the initial treatment of hand injuries, and to make use of recent technical advances at the very moment when disastrous infection in most cases can be avoided. This calls for skill and experience; but, more important still, it calls for spending more time on detailed surgery during initial treatment than has been customary hitherto.

Many severe hand injuries must be treated (and will undoubtedly continue to be treated) in hospitals where anaesthesiologists are not available. It is always desirable to avoid long general anaesthesia in patients who are in a poor physical state or whose general condition has not been determined. They may have a full stomach, general or pulmonary infection, alcoholism, or complicating injuries. The brachial plexus block — in our experience preferable with xylocaine—has many, but not all, of the advantages desired. It does not eliminate complications entirely, but neither does any anaesthetic. Nor is it easy to administer from a technical point of view. Without doubt it requires a certain amount of training before satisfactory results can be obtained. For the surgeon with sufficient training, however, the method is valuable, especially in surgery of the hand.

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DISCUSSION

Preservation and Use of Freeze-Dried Bone

(*Continued from page 872*)

In answer to Dr. Weaver's question, may we note that there is no appreciable difference in the sterility of freeze-dried bone as compared to frozen bone. We feel that this objection to freeze-drying as an added process in bone handling is valid. However, reasonable aseptic technique would result in no more contamination than in frozen bone. We are now investigating a technique for treating bone with cathode rays in an effort to sterilize the bone without substantial damage to the bone protein. This may result in an absolutely sterile product. It has been done with blood vessels[a] and we may be able to do it with bone.

As far as the crumbling effect of bone is concerned, that is true only of the cancellous bone, and it may be reconstituted with any fluid, whether it be saline or plasma or the patient's hematoma, to its previous physical properties.

We wish to thank the discussors for their comments.

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RUPTURE OF THE BRACHIAL ARTERY ACCOMPANYING DISLOCATION OF THE ELBOW OR SUPRACONDYLAR FRACTURE

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Recent experiences with two cases of rupture of the brachial artery, in one of which the rupture was associated with a compound anterior dislocation of the elbow and in the other of which the rupture was associated with a supracondylar fracture, prompted further inquiry into the subject of rupture of the brachial artery in conjunction with these injuries about the elbow, in an attempt to assay the frequency of this complex injury, together with the methods and results of treatment.

Rupture of the brachial artery in association with dislocation of the elbow or supracondylar fracture is rare, judging from the number of such cases reported in the literature. Eliason and Brown collected twenty-one cases, including their own, of arterial injury resulting from dislocation of the elbow. They also found records of reference to two additional cases, but they were unable to obtain the original articles. In sixteen of this group of twenty-one cases, arterial injuries were associated with compound dislocations; and, in fifteen, the brachial artery was the vessel injured. In five, the arterial injury occurred below the bifurcation of the brachial artery; in three it involved the ulnar artery alone; in one, the radial artery alone; and in one both the radial and the ulnar arteries. In one case, the ruptured vessel proved to be a vein. Because reports of only four of the twenty-one cases have been published since the turn of the century, and because only four were in the English language, it is difficult to ascertain the precise details in each case. However, almost all of the dislocations of the elbow were associated with one or more fractures. Whether the brachial artery was severed, lacerated, or contused, in the fifteen cases in which the brachial artery was injured, is not stated.

As far as can be determined, only three cases of rupture of the brachial artery have been reported in which the diagnosis has been verified at surgical exploration and dislocation of the elbow without any accompanying fractures has been found. The first, which was reported by Marnham in 1934, was a case of simple posterior dislocation associated with the severance of the brachial artery one-half of an inch (1.27 centimeters) above its bifurcation. Treatment was carried out about one hour after the injury and consisted in surgical exploration of the antecubital space, ligation of the ends of the torn vessel, and reduction of the dislocation. The radial pulse reappeared within three weeks, and the function of the joint was almost normal four months after the injury.

The second case was reported by Jackson in 1940. In this instance, the dislocation was simple and anterior. Reduction was accomplished within fifteen minutes of the injury, and, after two hours of medical treatment for progressive vascular insufficiency of both the forearm and hand, the antecubital space was explored surgically. Both ends of the severed brachial artery were found, and active bleeding from the proximal end was observed. A clot in the distal stump was sucked away, after which an end-to-end anastomosis of the artery was performed. A cuff from the brachial vein was utilized to reinforce the anastomosis. Immediately after the operation, the color of the extremity improved, and the radial pulse became palpable. Eight months postoperatively, the patient had a moderate limitation of motion of the elbow, but the blood supply to the forearm and hand appeared to be entirely normal.

The third case, mentioned by Mathewson in his discussion of Jackson's report, was that of rupture of the brachial artery in association with a compound anterior dislocation

of the elbow. After preliminary reduction of the dislocation, an end-to-end anastomosis of the severed artery was accomplished. Thereafter, the radial pulse was faintly palpable for four days; it then disappeared entirely and became palpable once again on the eleventh day after the operation. This was interpreted as an indication of thrombosis at the arterial suture line, with the ultimate restoration of the radial pulse through collateral arterial channels. That a strong radial pulse can result from collateral blood supply alone was recently demonstrated when one of the authors (Janes) removed an aneurysm of the upper brachial artery, after ligation and division of the afferent and efferent trunks, without any palpable decrement of the radial pulse.

Although there have been a number of reports of arterial spasm in association with supracondylar fractures, as reviewed by Montgomery and Ireland, we have been unable to find any reports in the English language of rupture of the brachial artery in these cases, verified at surgical exploration.

Four cases of rupture of the brachial artery in association with dislocation of the elbow joint or supracondylar fracture have been collected from the files of the Mayo Clinic and are summarized in this paper. The first two were recently encountered by the authors.

REPORT OF CASES

CASE 1.—A white man, nineteen years old, was hospitalized on October 5, 1950, four hours following an injury to his right elbow, sustained by catching his right arm in a corn-binding machine. On admission, the patient was fully alert. Blood pressure was 138 systolic and 88 diastolic; pulse rate was 68 beats per minute. General physical examination, when the right arm was excluded, showed nothing of significance. The patient was unable to carry out any movements of the right elbow, wrist or hand. Except for a small area in the vicinity of the anatomical snuff box, where sensation was diminished but present, there was anaesthesia of the entire hand. The elbow was bandaged; but distally, the forearm and hand appeared pallid and slightly cyanotic. No radial or ulnar pulses were palpable. Roentgenograms revealed an anterior and medial dislocation of the radius and ulna at the elbow, without any associated fractures (Figs. 1-A and 1-B). The patient was taken to the operating room, where removal of the bandage revealed a compound dislocation of the elbow. With the patient under pentothal sodium anaesthesia, the dislocation was reduced, and the wound was thoroughly debrided. Exploration of the antecubital space was performed; there was complete avulsion of the brachialis and of the flexor and pronator muscles, near their origin from the medial epicondyle. The median and ulnar nerves were tautly stretched across the antecubital space, but appeared to be intact; the radial nerve was not seen. The brachial artery was completely severed. The proximal stump was easily identified at the uppermost margin of the wound by its pulsations. The lumen was firmly occluded by a fresh thrombus. Double ligation with O braided silk was performed. The distal end of the artery had retracted beyond the inferior limits of the wound, and was not seen. The flexor and pronator muscles were reattached, and the wound was closed. A modified Robert Jones dressing, with a posterior plaster splint, was applied.

After the operation, the right arm was maintained in a dependent position, and a heat cradle was placed over the patient's abdomen. In addition, 5 per cent. alcohol in a 5 per cent. solution of dextrose was administered by constant slow intravenous drip for the first twenty-four hours after the operation. Tetanus antitoxin was given, and procaine penicillin was administered daily for three weeks. Although the fingers of the right hand remained paler and cooler than those of the opposite extremity, it was apparent, after the first four or five days, that the collateral circulation was sufficient to maintain viability. The patient ran a low-grade fever for two and a half weeks, at the end of which period his temperature gradually reverted to normal. He was dismissed three weeks following the injury; the elbow at that time was supported at about 145 degrees by means of a long cast applied over bulky dressings.

Ten days later, the fever recurred, and a large amount of foul-smelling drainage exuded through the dressings. The medial portion of the wound from the compound dislocation was found to have disrupted with the outpouring of liquefied, necrotic muscle, fat, and connective tissue. Dressings and a long cast were reapplied. Penicillin therapy was reinstituted for one week and the fever terminated abruptly. Drainage diminished progressively, and the wound gradually closed in from the bottom with healthy granulations. The color of the forearm and hand appeared normal, and the radial pulse, although diminished in intensity, was easily palpable. At the present time, sensation is returning to the hand and fingers, and the patient is able to carry out some active motion at the elbow and wrist. Intensive physical therapy is planned.

In this case, in addition to severance of the brachial artery, there was extensive laceration and contusion of the soft tissues of the antecubital space, with the result that

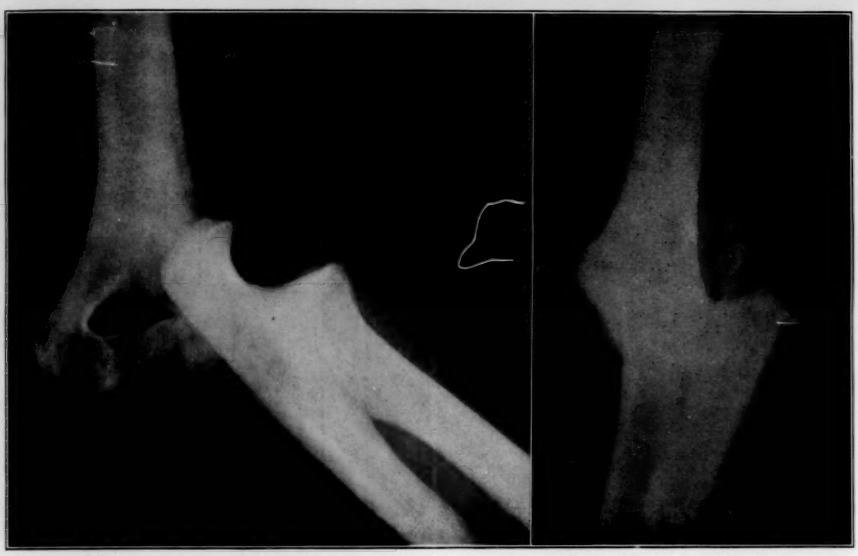

FIG. 1-A FIG. 1-B

Case 1. October 5, 1950. Roentgenograms show an anterior and medial dislocation of the radius and ulna at the elbow, without any associated fractures.

the collateral circulation about the elbow was seriously impaired. Accordingly, the viability of the extremity was in doubt immediately after the injury and the reparative surgery.

CASE 2.—A white boy, six years old, was hospitalized on October 14, 1950, three and a half hours after injuring his left arm in a fall from a tree. Immediately following the injury, he was seen by his family doctor, who splinted the arm and referred him to the Clinic for hospitalization.

On admission, the patient was fully alert. Blood pressure was 122 systolic and 78 diastolic, and the pulse rate was 110 beats per minute. General physical examination revealed nothing of significance except the condition of the left arm. The left elbow was ecchymotic and greatly swollen. The forearm, hand, and fingers appeared pallid and slightly cyanotic, and neither radial nor ulnar pulses were palpable. There were no lacerations or abrasions, and there was no evidence of nerve injury. Roentgenograms revealed a supracondylar fracture with considerable posterior displacement of the distal fragment and transverse fractures of both bones of the forearm in the lower thirds (Figs. 2-A and 2-B).

Because of the tense swelling about the elbow and the absence of pulses at the wrist, immediate exploration of the antecubital space was deemed necessary. This was carried out under ether-nitrous oxide anaesthesia. Immediately upon incision of the skin and subcutaneous tissues, a large amount of fresh blood with clots was released. There was considerable contusion of the soft tissues. The median nerve was readily located and appeared to be intact. Despite good exposure and careful exploration, the brachial artery was nowhere to be found. The absence of the peripheral pulses, the large amount of blood within the antecubital space and the absence of the artery on surgical exploration indicated that it had been avulsed at the time of injury and that the divided ends had retracted subsequently. Extension of the incision and further dissection in an attempt to locate the ends of the artery were thought to be unwarranted at the time. The supracondylar fracture was reduced by use of metal hooks, and no internal fixation was employed. The incision was closed.

Because any attempt at a closed reduction of the fractured radius and ulna might serve to redisplace the supracondylar fracture, an open reduction of the fractured radius was elected. This was quickly accomplished through a short incision over the volar surface of the lower third of the bone; again metal hooks were used. Once reduced, the fracture seemed quite stable and no internal fixation device was employed. The incision was closed, and a modified Robert Jones protective dressing was placed on the left arm with the elbow supported just above a right angle by a posterior plaster splint. Immediately after the operation, the color of the fingers was much improved, although the pulse could not be palpated.

After the operation, the patient was placed in a warm room (90 to 100 degrees, Fahrenheit) with the left arm in a slightly dependent position for the first forty-eight hours. By then it was apparent that the collateral circulation to the forearm and hand was easily sufficient. A total of 300,000 units of aqueous pro-

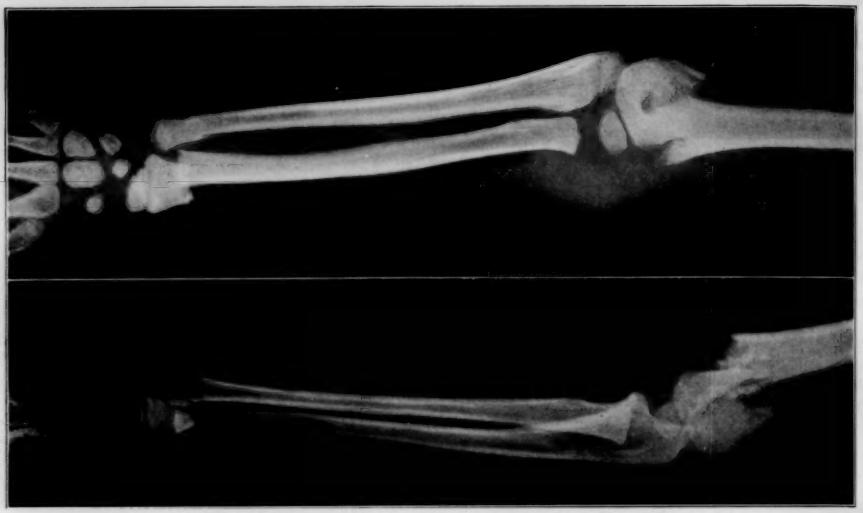

FIG. 2-A FIG. 2-B

Case 2. October 14, 1950. Roentgenograms show a supracondylar fracture with considerable posterior displacement of the distal fragment and transverse fractures of both bones of the forearm in the lower thirds.

caine penicillin was administered daily. By the end of the first week after the operation, the swelling about the elbow had receded, and a long cast was applied to the arm. Roentgenograms taken through the cast shortly thereafter revealed that the supracondylar fracture had resumed some of its original deformity. Accordingly, at the end of the following week, when the incisions were firmly healed, gentle manipulation of the supracondylar fracture under anaesthesia was attempted, without success. Fortunately, the bones of the forearm remained in good alignment. Moleskin tapes were then placed on the upper arm and forearm, and two-pound outrigger traction was applied to both. This was maintained for two weeks, after which a long cast was again applied. On November 30, 1950, a little more than six weeks following injury, the cast was finally removed. Roentgenograms showed satisfactory alignment of all the fractures with good callus formation. At this time, the radial and ulnar pulses were both palpable.

The occurrence of rupture of the brachial artery as a complication of simple supracondylar fracture has not, to our knowledge, been previously recognized. Prompt release of tension from hematoma within the antecubital space undoubtedly promoted the rapid development of collateral circulation, and may have averted either gangrene or a Volkmann contracture in this case.

CASE 3.—A white youth, fourteen years old, was first seen at the Clinic on July 7, 1932, about forty-eight hours after sustaining a compound left supracondylar fracture in an auto accident. Within one hour of the injury, the patient was hospitalized elsewhere. The fracture was reduced, and the wound on the posteromedial aspect of the elbow was cleansed and debrided. Exploration of the antecubital space revealed that the brachial artery was severed. Both the proximal and distal ends were easily located, and their lumina were found occluded by fresh thrombi. Ligation of each end was performed. In addition, the biceps tendon and the brachialis were ruptured; these structures were repaired. The median and ulnar nerves were intact, although the latter was contused. The wound was loosely closed with drainage. Tetanus antitoxin was administered. After operation, the patient's condition was good. Forty-eight hours later he was transferred to the Mayo Clinic for further care.

On admission, physical examination disclosed nothing of importance except for the condition of the left arm. Circulation to the left forearm and hand seemed entirely adequate. There was partial numbness of the left fourth and fifth fingers, together with some weakness of the interossei muscles. These findings were indicative of incomplete ulnar palsy. Roentgenograms revealed a fracture of the lower third of the left humerus, approximately two inches (5.08 centimeters) above the elbow, with anterior and medial displacement of the proximal fragment. Further manipulation was deemed inadvisable, and an aeroplane splint was applied. Six days after injury, the patient had an episode of serum sickness, which was controlled with ephe-

drine and amytal. The wound healed uneventfully. The arm was maintained in an aeroplane splint for four weeks, after which a plaster spica was applied. At the time of dismissal, on August 5, 1932, the circulation was entirely normal, and the supracondylar fracture was uniting with only moderate anterior and medial displacement of the proximal fragment. The partial ulnar palsy had almost entirely disappeared.

CASE 4.—A white boy, twelve years old, was hospitalized on August 2, 1930, within an hour after sustaining a compound left supracondylar fracture and compound transverse fractures of both bones of the left forearm, as the result of a fall from a bicycle. Immediately after the injury, the patient bled profusely from the wound in the antecubital space. He was rushed to a nearby physician, who applied a tourniquet and referred him to the Clinic for hospitalization.

General physical examination on admission disclosed nothing of importance except for the left arm. The patient was taken to the operating room where, under ether anaesthesia, the wound in the antecubital space was cleansed, debrided, and explored. The proximal fragment of the humerus was projecting from the skin wound. The fracture was reduced, and subsequent exploration revealed that the biceps and brachialis were almost completely severed. The median nerve was tightly stretched but not torn. The brachial artery was completely severed, and the ends had retracted into the uppermost and lowermost limits of the antecubital space. There was no free bleeding. Both ends of the brachial artery were found and ligated. The tear in the muscles was repaired as well as possible, and the wound was loosely closed. The radius and ulna, which were fractured transversely at the junction of the middle and lower thirds, were then manipulated after preliminary débridement and closure of a compounding laceration on the ulnar side of the forearm. A long cast was applied to the arm. Tetanus antitoxin was administered.

After the operation, the patient ran a septic course, with daily elevation of temperature to 103 degrees Fahrenheit for the first nine days. The circulation to his forearm and hand, however, seemed entirely adequate. The long cast was removed one and one-half weeks after injury because of malalignment of the fractured bones. The supracondylar fracture was manipulated into satisfactory position, and an open reduction of the fractured bones of the forearm was performed, with fixation of the ulna by means of a four-hole Lane plate. A long cast was reapplied to the arm. Subsequently, the antecubital wound ceased draining and healed. The wound in the forearm drained persistently, however, and on November 11, 1930, the Lane plate, together with three small sequestra, was removed. Thereafter, the wound healed uneventfully. Although circulation to the forearm and hand appeared normal, and the wounds and fractures ultimately healed, the patient was left with a markedly impaired arm, due to severe persistent limitation of motion of both the elbow and wrist joints.

In Cases 3 and 4, severance of the brachial artery occurred in association with compound supracondylar fractures.

COMMENT

It is our impression that rupture of the brachial artery in association with dislocation of the elbow or supracondylar fracture is probably more common than the number of cases reported in the literature indicates. Except in rare instances, rupture of the brachial artery has been recognized only when débridement and exploration have been necessary. However, recognition of rupture of the brachial artery in cases of simple fracture or dislocation is perhaps even more important, as is illustrated in Case 2, because hemorrhage into the closed antecubital space may produce so much tension that a large portion of the collateral blood supply may be blocked and either gangrene or Volkmann's contracture may possibly ensue.

Rupture of a brachial artery, in association with dislocation of the elbow or supracondylar fracture, should be suspected whenever there is a compound wound of the antecubital space; or, in the case of closed injuries, whenever there is swelling and ecchymosis about the elbow together with obliteration of the radial and ulnar pulses. Accurate distinction between traumatic vasospasm or arterial contusion, and laceration or division of the artery can be achieved only by surgical exploration.

The treatment of rupture of the brachial artery, once the condition has been recognized, is relatively simple. As has been pointed out [3], any artery within the upper extremity may be ligated and divided with relative impunity, because of the presence of superabundant collateral circulation. Accordingly, unless a satisfactory closure of the lacerated arterial wall, or an accurate end-to-end anastomosis of the severed vessel can be performed, simple ligation and division of the lacerated artery, or ligation of both ends of the severed

vessel, is the procedure of choice. Vein grafts have been utilized to bridge the gap between the retracted ends of a severed brachial artery; but this is an unnecessary and time-consuming procedure, and may ultimately result in thrombosis at the site of anastomosis. Ligation may be safely accomplished by utilizing fine braided silk suture material and employing simple ligature proximally and a suture-ligature distal to this, after any blood present is milked out of the lumen of the small intervening segment. If, in order to preserve collateral circulation, it is essential to spare as much of the brachial artery as possible, then suture of the ends of the severed vessels with fine arterial silk on an atraumatic needle can be accomplished.[8] Either of these methods will avert the danger of secondary hemorrhage. A modified Robert Jones protective dressing has proved to be a satisfactory swathe for extremities after vascular injuries.[3]

Postoperatively, the blood pressure should be maintained at or near a normal level, and heating or elevating the involved limb should be avoided. A heat cradle over the abdomen, together with administration of papaverine or alcohol, may be utilized to some advantage in promoting collateral circulation, provided that the blood pressure is maintained at a normal level. Paravertebral sympathetic block is transient in effect and has not been necessary. As pointed out by Linton, division of the artery *per se* accomplishes an effective periarterial sympathectomy, to which sympathetic block or sympathetic ganglionectomy, as an emergency procedure, adds little benefit. A booster dose of tetanus toxoid or tetanus antitoxin, together with a suitable antibiotic agent, should be administered routinely, since the combination of devitalized tissue plus circulatory impairment, which is inevitable in these cases, sets the stage for infection, particularly with microaerophilic or anaerobic organisms. Anticoagulants are unnecessary and, in any event, should not be employed in the presence of a large amount of contused tissue.

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EVALUATION OF HEALED COLLES' FRACTURES

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An analysis of a series of healed Colles' fractures has been made for a twofold purpose: to determine, if possible, what factors are responsible for unsatisfactory end results, and to evaluate a method of treatment widely advocated and commonly used. The fractures in this series were treated at an active general hospital by general surgeons, orthopaedic surgeons, and resident surgeons. The follow-up results are believed to be representative of end results obtainable in any institution in which this fracture is similarly treated and studied.

METHOD OF STUDY

At the time of the evaluation examination a complete fracture history was taken and a physical examination was made of both wrists, including accurate measurement of all wrist motions with a goniometer according to the method of Cave. A series of five roentgenograms was then made of both the normal and the injured wrist, from the following positions: (1) anteroposterior, (2) lateral, (3) oblique, (4) with the hand in complete radial deviation, and (5) with the hand in complete ulnar deviation. These roentgenograms, together with the prereduction, postreduction, and follow-up films, gave us complete roentgenographic coverage of all phases of the fracture. In addition an interval film, made at the time plaster fixation was discarded, was available for study in 50 per cent. of the cases.

The components of a Colles' fracture include dorsal tilt of the distal radial fragment and loss of the normal medial tilt of the distal end of the radius, both measured in degrees, and shortening of the radius, measured in millimeters. The value for each component was computed on each of the roentgenograms by direct measurement (Fig. 1). This method of measurement made it possible to observe the behavior of each fracture component as healing progressed (Figs. 2-A to 2-E).

SELECTION OF CASES AND METHODS OF TREATMENT

This method of study was applied to sixty cases. Three constants were maintained in selecting these cases:

1. Each had had a true Colles' fracture;
2. Each was re-examined one year after the fracture or later;
3. The method of reduction, type of immobilization, and follow-up care of the original injury had been the same in each case.

This was a series of fractures in adults averaging fifty-three years of age. The ratio of females to males was three to one. The follow-up period ranged from twelve to forty-six months, with an average of eighteen months.

Each of the fractures was first treated by the usual method of closed manipulation. Local anaesthesia was used in two thirds of the cases and a general anaesthetic in the others. Fluoroscopic control was used in one third. Immobilization was effected by means of lightly padded dorsal and volar plaster splints held in place by a circular gauze bandage. Splints extended from just proximal to the metacarpal heads to the upper portion of the forearm just below the elbow. The injured wrist was held in the position of palmar flexion and ulnar deviation for an average period of two weeks. The splints were then re-applied with the wrist in neutral position. The total period of immobilization averaged six weeks.

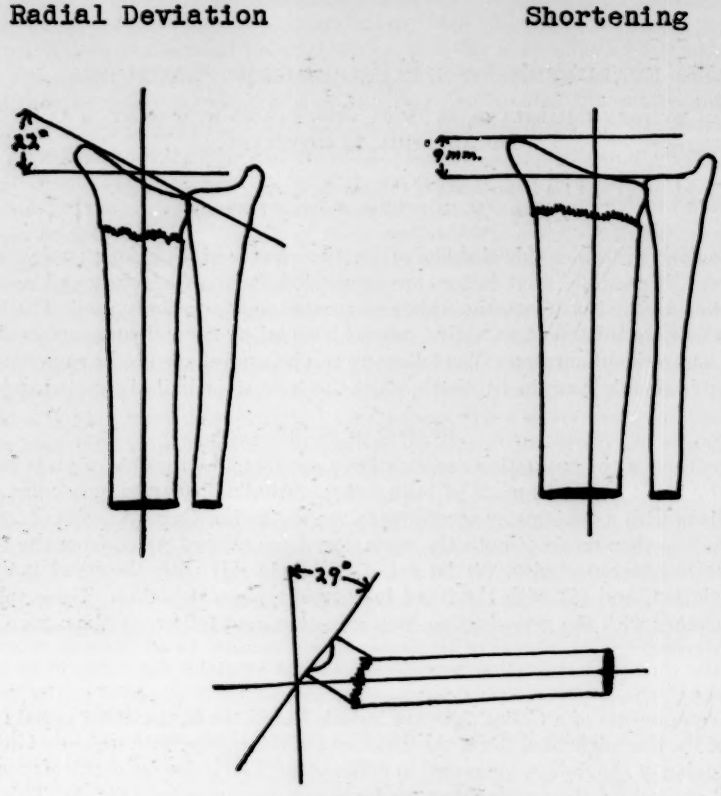

FIG. 1

Method used for measuring the value of each component. The appropriate angle or distance is read directly from the roentgenograms after these lines are drawn. The numbers indicated are measurements selected at random for illustrative purposes.

FUNCTIONAL END RESULTS

Any method of fairly and accurately evaluating functional end results in fractures must include all aspects of the fracture and any sequelae. Therefore, it must take into account residual deformity, the subjective evaluation of the patient, the objective findings, and any complications arising directly from the fracture. For the purposes of this investigation a reasonably complete and exhaustive method of evaluating final functional end results was devised. This is a point system based on authoritative disability evaluation charts [4], which takes into account all possible factors and gives each a point value relative to one another. Analysis of cases according to this point system has led to the formation of certain point ranges for each end-result group, and has thus provided a constant, rigid yardstick for evaluating each fracture (Table I). By applying this yardstick to the series of fractures it was possible to tabulate functional end results (Table II). At the end of the follow-up period, which averaged eighteen months, satisfactory results had been obtained in 68.3 per cent. of cases and unsatisfactory results in 31.7 per cent. The functional end results obtained in this common and often lightly regarded fracture were not felt to be very commendable and prompted an analysis of the following related factors.

The following roentgenograms represent the course of a typical fracture and indicate the method of measuring the fracture components at each stage.

FIG. 2-A
Measurements made on pre-reduction film.

FIG. 2-B
Measurements on x-ray made immediately after reduction.

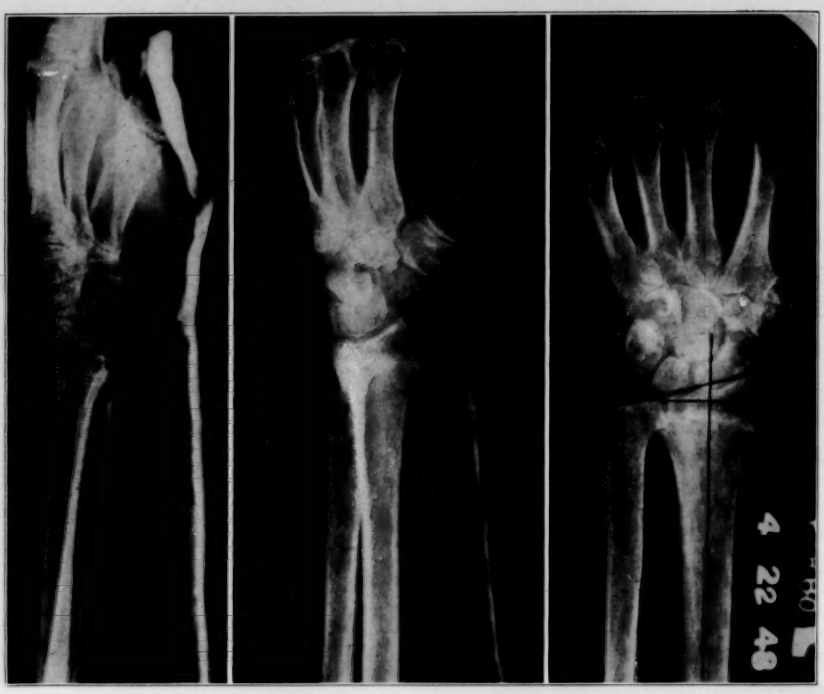

FIG. 2-C

Same patient. Measurements made on roentgenogram taken immediately after plaster was removed. (Average time of removal was six weeks after fracture.)

TYPES OF FRACTURE

It has been said that no two Colles' fractures are alike. Although this is not strictly true, the fractures may be grouped into several distinct types; a classification of these has been described [5]. For our purposes the fractures in this series were divided into three groups on the basis of the roentgenograms made before reduction:

Group I. Simple Colles' fracture with no involvement of the radial articular surface (seven cases, 12 per cent.).

Group II. Comminuted Colles' fracture with fractures of the radial articular surface in which the fragments were not displaced (twenty-seven cases, 45 per cent.).

Group III. Comminuted Colles' fracture with fractures of the radial articular surface in which the fragments were displaced (twenty-six cases, 43 per cent.).

This method of classification is important because the end result will depend to some extent upon the type of fracture sustained. Comminuted fractures are the most frequent, forming 88 per cent. of the cases in this series. When the type of fracture incurred is analyzed in relation to the ultimate end result, the bulk of unsatisfactory results will, of course, be found in the two groups with comminuted fractures (Table II). Unsatisfactory results were found in only 14 per cent. of the Group I fractures, while in Groups II and III the number rose to 27 per cent. and 42 per cent. respectively. It is evident that the type of fracture incurred is a factor in the prognosis.

COMPONENTS OF FRACTURE

A. Dorsal Tilt

The behavior of the actual fracture components themselves was next investigated. In the normal wrist the lower end of the radius has a distinct anterior concavity and the

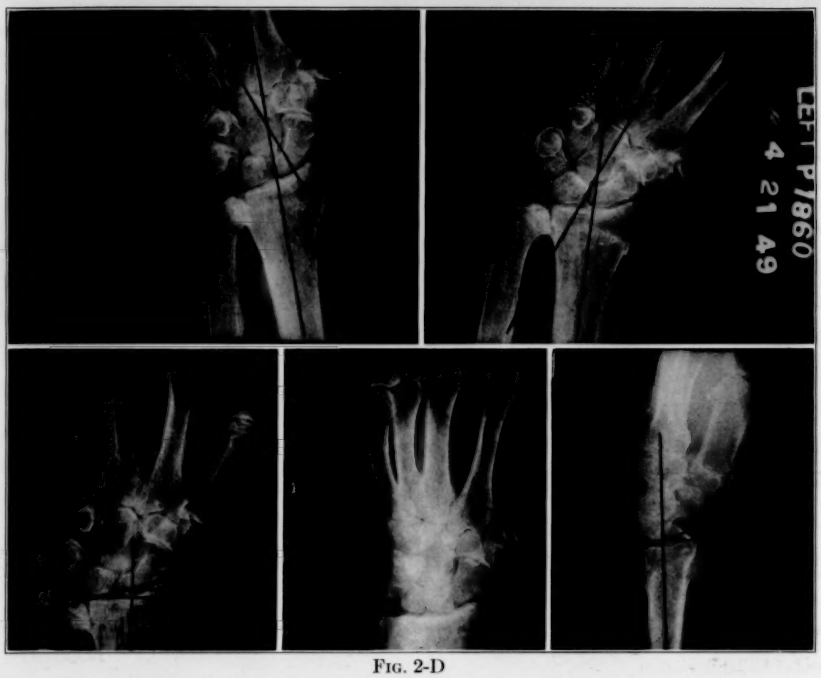

FIG. 2-D

Measurements made for evaluation of disability (average, 18 months after fracture).

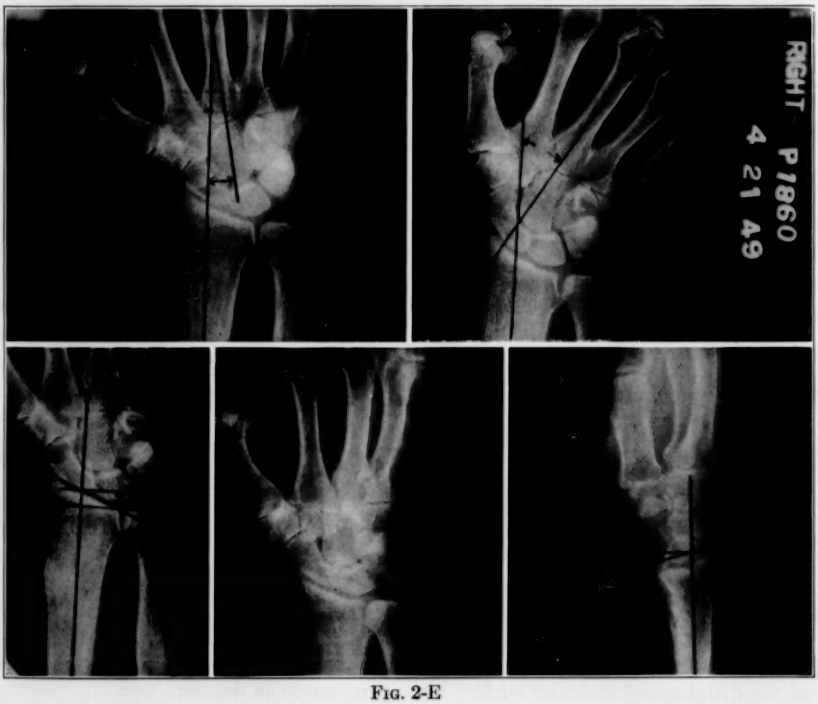

FIG. 2-E

Measurements of normal right hand, made at same time as roentgenogram shown in Fig. 2-D.

TABLE I

POINT SYSTEM USED TO EVALUATE END RESULTS OF HEALED COLLES' FRACTURES

Result	Points
Residual Deformity	
Prominent ulnar styloid	1
Residual dorsal tilt	2
Radial deviation of hand	2 to 3
Point range	0 to 3
Subjective Evaluation	
Excellent. No pain, disability, or limitation of motion	0
Good. Occasional pain, slight limitation of motion, no disability	2
Fair. Occasional pain, some limitation of motion, feeling of weakness in wrist, no particular disability if careful, activities slightly restricted	4
Poor. Pain, limitation of motion, disability, activities more or less markedly restricted	6
Point range	0 to 6
Objective Evaluation *	
Loss of dorsiflexion	5
Loss of ulnar deviation	3
Loss of supination	2
Loss of palmar flexion	1
Loss of radial deviation	1
Loss of circumduction	1
Pain in distal radio-ulnar joint	1
Point range	0 to 5
Complications	
Arthritic change	
Minimal	1
Minimal with pain	3
Moderate	2
Moderate with pain	4
Severe	3
Severe with pain	5
Nerve complications (median)	1 to 3
Poor finger function due to cast	1 to 2
Point range	0 to 5
End-result point ranges	
Excellent	0 to 2
Good	3 to 8
Fair	9 to 20
Poor	21 and above

* The objective evaluation is based upon the following ranges of motion as being the minimum for normal function: dorsiflexion, 45 degrees; palmar flexion, 30 degrees; radial deviation, 15 degrees; ulnar deviation, 15 degrees; pronation, 50 degrees; and supination, 50 degrees.

articular surface is directed slightly forward as well as downward. This so-called volar tilt of the distal radial articular surface can be measured in degrees.

The normal range in our series was +1 degree to +21 degrees, with an average volar

TABLE II

END RESULTS AT TIME OF FOLLOW-UP EXAMINATION
(Results for total number of cases and for each of the three groups)

End Results	Total Cases		Group I (7 Cases)		Group II (27 Cases)		Group III (26 Cases)	
	No.	*Per cent.*	*No. of Cases*	*Per cent.*	*No. of Cases*	*Per cent.*	*No. of Cases*	*Per cent.*
Excellent	13	22	3	43	9	33	1	4
Good	28	47	3	43	11	40	14	54
Fair	17	28	1	14	6	22	10	38
Poor	2	3	0	0	1	5	1	4

tilt of +11 degrees. After a Colles' fracture the distal radial fragment is displaced and tilted backward. This dorsal tilt was measured in minus degrees.

Study of the position of the distal radial fragment in this plane during the several phases of the fracture treatment showed, first of all, that the original amount of dorsal tilt has no appreciable effect on the ultimate end result. A comparable and apparently satisfactory reduction was carried out in all groups as far as this component was concerned (Table III). It will be noted, however, that this component does not stay reduced. As healing progresses, this factor in the reduction is lost, and residual dorsal tilt is found in

TABLE III

DORSAL TILT AS SHOWN IN ROENTGENOGRAMS

End Result	X-ray Before Reduction (*Degrees*)	X-ray After Reduction (*Degrees*)	Interval X-ray (In 50 per cent. of all cases) (*Degrees*)	Follow-up X-ray (*Degrees*)
Excellent	−15	+6	+3	0
Good	−21	+2	+3	−2
Fair	−20	+4	−2	−5

the end results of all cases except those in the excellent group. It is evident, then, that this component of the fracture is not being adequately reduced. In no group has the dorsal tilt been corrected sufficiently to compensate for the loss which will occur as healing progresses. Since the functional end result becomes worse as the amount of residual dorsal tilt increases, the minimum standard for this component of the reduction should be an average volar tilt of at least +11 degrees in order to compensate adequately for the loss of correction which will occur.

The fact that some loss of this part of the reduction occurs between the postreduction

TABLE IV

RADIAL DEVIATION AS SHOWN IN ROENTGENOGRAMS
(Normal deviation: 23 degrees)

End Result	X-ray Before Reduction (*Degrees*)	X-ray After Reduction (*Degrees*)	Interval X-ray (In 50 per cent. of all cases) (*Degrees*)	Follow-up X-ray (*Degrees*)
Excellent	20	22	20	20
Good	16	18	16	16
Fair	19	21	19	19

period and the time of the interval film—that is, during the period of immobilization—throws some doubt on the adequacy of immobilization. The fact that even greater loss of this component occurs between the time of the interval film and the follow-up film has also led us to question whether the period of immobilization—an average of six weeks in this series—has been sufficient.

B. Radial Deviation

The second characteristic pathological finding in a Colles' fracture is some loss of the normal inward tilt of the distal end of the radius, due to impaction and radial deviation of the distal fragment. Normally in our series this inward tilt ranged from 13 to 30 degrees, with an average of 23 degrees. After a Colles' fracture, this angle is decreased and in our series has been found to be as low as 4 degrees.

From a review of the several phases of the fracture treatment it is evident that the behavior of this component follows a pattern identical to that of residual dorsal tilt (Table IV). A certain amount of correction is obtained at the time of reduction, but, like dorsal tilt, this component of the fracture does not stay reduced. In fact, this part of the reduction is lost completely in all groups between the postreduction and interval films, that is, while the wrist is in the cast. On the interval film the fractures in all groups show an amount of residual radial deviation equal to that of the original injury. Again this is evi-

TABLE V

EXTENT OF SHORTENING AS SHOWN IN ROENTGENOGRAMS

End Result	X-ray Before Reduction (*Millimeters*)	X-ray After Reduction (*Millimeters*)	Interval X-ray (In 50 per cent. of all cases) (*Millimeters*)	Follow-up X-ray (*Millimeters*)
Excellent	2.0	1.3	2.3	2.2
Good	3.7	1.3	3.4	3.3
Fair	2.8	1.4	3.5	3.9

dence that the method of immobilization used is unsatisfactory. In the light of these facts, we cannot say that the original reduction of this component of the fracture was adequate. It has been said that the normal inward tilt of the distal end of the radius averages 23 degrees. In no group has radial deviation been corrected sufficiently at the time of the original reduction to compensate for the loss which will occur with the type of immobilization used. The minimum standard for this component of the reduction should be the average value of at least 23 degrees. The amount of residual radial deviation, however, unlike dorsal tilt, does not appear to have any appreciable relationship to the end result, as was seen on the follow-up films of cases in our series.

In a high percentage of cases radial deviation is associated with a rotation of the distal radial fragment on its long axis in a direction of supination. As the fracturing force strikes the pronated hand, the distal radial fragment is displaced backward. This backward displacement produces tension on the fibrocartilage, with the result that the lower fragment is pivoted around the head of the ulna in a direction of supination. This supination twist of the distal radial fragment can be seen roentgenographically if both bones are shown on the anteroposterior roentgenogram. Such a picture would show a normal anteroposterior view of the upper end of the radius with a normal lateral view of the lower end of the radius [3]. Detection of this twist in the usual roentgenogram of the lower end of the radius is not easy. In the usual lateral view the distal fragment will appear to be displaced backward. The anteroposterior view will show apparent radial deviation of the distal fragment, which seems to overlap the proximal fragment on its outer side, and to be

slightly broadened in comparison with it. However, Mayer's experiments demonstrated that "no such backward or radial displacement was in fact present and these appearances are typical of a severe supination-twist".

In our series 52 per cent. showed it and 48 per cent. did not. Displacement was equally distributed among the end-result groups. The number of cases losing the radial deviation component of the reduction during immobilization was the same (65 per cent.) in the group with supination twist as in the group without this complication. It has been found, however, that those patients with supination twist show a greater loss of the inward tilt of the distal end of the radius at the time of fracture. The effect of supination twist is apparently counteracted by immobilization during the healing period. This evidence would lead to the conclusion that supination twist of the distal radial fragment at the time of fracture does not influence the functional end result as long as reduction of this component of the fracture can be adequately maintained. Its only effect would seem to be that it increases the difficulty of adequately maintaining the normal inward tilt of the distal radial fragment. It forms the logical basis for immobilizing these fractured wrists in pronation.

C. Shortening

The third component of a Colles' fracture to be examined is shortening of the radius. Shortening results from a combination of impaction, loss of the normal inward radial tilt, and absorption of bone at the fracture site. From a study of Table V it can be seen that, regardless of the extent of original shortening, a comparable reduction has been achieved in all groups. However, this component of the fracture, like the other two already discussed, does not stay reduced. In all groups this part of the reduction is completely lost between the time of the postreduction film and the interval film,—that is, while the wrist is in the cast. In all groups the amount of shortening shown on the interval film was equal to that present immediately after the original injury. Again this is evidence that the method of immobilization is inefficient.

It is difficult to determine whether or not this component of the fracture has been adequately reduced. Certainly reduction has not been complete, for all groups show a residual shortening, and although this is inconsiderable, it increases during the healing period. As much shortening as possible, then, must be corrected at the time of reduction, since, with the type of immobilization used in this series, this length will not be completely maintained during the healing period.

D. Distal Radio-Ulnar Joint

Loss of integrity of the distal radio-ulnar joint has been indicted as the cause for most of the poor results after this fracture [2, 7]. In the normal wrist, the integrity of the distal radio-ulnar joint is maintained by a triangular fibrocartilage. This fibrocartilage runs from the distal margin of the ulnar notch of the radius to the base of the ulnar styloid. In a Colles' fracture the breaking of the distal end of the radius, with its impaction and dorsal displacement, attenuates this fibrocartilage to a maximum degree and beyond, because of the volar displacement of the ulnar head. Two factors aid in preventing rupture of this ligament in a Colles' fracture. The first is avulsion of the medial posterior portion of the distal end of the radius, which contains the ulnar notch, and hence the insertion of the base of the triangular fibrocartilage; in our series this element of the fracture was present in 86 per cent. of the cases. The second factor is avulsion of the base of the ulnar styloid, and hence of the other insertion of the triangular fibrocartilage; this component of the fracture was present in 47 per cent. of our cases. The anatomical arrangement of this fibrocartilage explains the frequent occurrence of these fractures. Both of these types of fracture lead to subluxation of the distal radio-ulnar joint. Rupture of this fibrocartilage can be diagnosed when the integrity of the distal radio-ulnar joint is lost and neither of

these types of fracture has occurred. This complication did not arise in any of our cases.

In our series, the follow-up films of eighteen cases showed residual disruption of the distal radio-ulnar joint. Only six of these patients complained of any pain on supination or on compression of the distal radio-ulnar joint. The average loss of supination for the cases showing loss of integrity of the distal radio-ulnar joint was 20 degrees. In our analysis, 61 per cent. of these cases were listed among the satisfactory end results and 39 per cent. among the unsatisfactory results. This ratio is about the same as for the series as a whole. If this were the major cause for poor results, a much higher percentage of unsatisfactory results might be expected. Although loss of integrity of the distal radio-ulnar joint may be one cause of an occasional poor result, it is certainly not often a cause in the average case.

EFFICIENCY OF IMMOBILIZATION

Thus far, the evidence from a study of the components of Colles' fractures indicates that these fractures are being incompletely reduced. How efficient was the method of immobilization used in this series? Analysis of dorsal tilt, radial deviation, and shortening has shown that these components of the reduction are lost completely during the healing period. The cause must be inadequate immobilization. Further evidence that this method of immobilization is insufficient is furnished by the fact that a total of 33 per cent. of the cases showed a loss of volar tilt of 10 degrees or more during the healing period. A loss of more than 3 degrees of radial deviation was seen in 31 per cent. of all cases, and shortening of three millimeters or more occurred during the healing period in 30 per cent. of the cases. From these figures it would seem that the method of immobilization used in this series was an inefficient method of external fixation for the average Colles' fracture. Thus faulty immobilization is one of the chief factors in this series operating against the achievement of satisfactory end results. This is borne out by the fact that 62 per cent. of the excellent end results showed no loss of reduction during the healing period. In the good group the total dropped to 40 per cent., and in the fair group to only 23 per cent. of cases.

TABLE VI

EFFECTS OF RESIDUAL DORSAL TILT ON DORSIFLEXION AND PALMAR FLEXION

Volar-Dorsal Tilt (Normal: +11 degrees) (*Degrees*)	Dorsiflexion (Normal: 61 degrees) (*Degrees*)	Palmar Flexion (Normal: 54 degrees) (*Degrees*)
+11 to 0 (26 cases)	52	50
0 to −10 (21 cases)	56	44
−11 and above (13 cases)	52	33

FUNCTION STUDY

It has been stated that residual dorsal tilt is detrimental to function because of its deleterious effect upon dorsal and palmar flexion of the wrist joint. Likewise residual

TABLE VII

MEASUREMENT OF EFFECTS OF RESIDUAL RADIAL TILT ON RADIAL AND ULNAR DEVIATION

Radial Tilt (Normal: 23 degrees) (*Degrees*)	No. of Cases	Radial Deviation (Normal: 20 degrees) (*Degrees*)	Ulnar Deviation (Normal: 33 degrees) (*Degrees*)
23 to 18	32	20	31
17 to 13	22	20	28
12 and below	6	24	24

TABLE VIII

RADIAL AND ULNAR DEVIATION

Shortening (*Millimeters*)	No. of Cases	Radial Deviation (Normal: 20 degrees) (*Degrees*)	Ulnar Deviation (Normal: 33 degrees) (*Degrees*)
0 to 3	36	19	31
4 or more	24	21	26

radial tilt and shortening have been condemned because of their effect upon lateral motions of the hand and wrist [4, 7]. These effects have been seen often enough to validate what originated as a clinical impression. However, no effort has been made to evaluate these effects in a quantitative way. The authors felt, therefore, that this study afforded an excellent opportunity of measuring the effect of each residual component on function. The normal averages for dorsiflexion and palmar flexion were obtained from the uninjured wrist. The normal averages for radial and ulnar deviation of the wrist were obtained from the follow-up control films of the uninjured wrist.

The effects of residual dorsal tilt on dorsiflexion are summarized in Table VI. The normal average dorsiflexion of the uninjured wrist in this series was 61 degrees. In those cases in which the position of the distal part of the radius ranged from normal volar tilt to 0 degrees on the follow-up films, dorsiflexion averaged 52 degrees. This slight decrease below normal is attributable, we believe, to the stiffening effect of trauma and immobilization on the soft parts. A slight increase in dorsiflexion—to 56 degrees—was seen in those cases in which dorsal tilt ranged from 0 degrees to −10 degrees. This increase is due to the fact that residual dorsal tilt shifts the arc of this motion backward so that in full extension the normal limit theoretically will be exceeded. Dorsiflexion also averaged 52 degrees in those cases which had a residual dorsal tilt of −11 degrees or more. In these cases it seems reasonable to suppose that the backward shift of the motion arc was offset by the effect of more severe trauma. In general, residual dorsal tilt had no appreciable effect on dorsiflexion in our cases.

The normal average palmar flexion of the uninjured wrist in this series was 54 degrees. In those cases in which position of the distal end of the radius ranged from normal volar tilt to 0 degrees on the follow-up films, palmar flexion averaged 50 degrees. A drop to 44 degrees was seen in those cases ranging from 0 degrees to a residual dorsal tilt of −10 degrees. Palmar flexion further decreased to 33 degrees in those cases showing residual dorsal tilt of −11 degrees or more. In general, residual dorsal tilt has a decreasing effect on palmar flexion, and in cases with a residual dorsal tilt of −11 degrees or more the decrease is significant.

The effects of residual radial tilt on radial and ulnar deviation of the hand are summarized in Table VII. Normal radial deviation in our series averaged 20 degrees and ulnar deviation 33 degrees. Residual radial tilt was not found to have any appreciably significant effect on lateral motions at the wrist in our cases. Residual shortening appears to have little more effect on lateral motions at the wrist than does radial tilt (Table VIII). In general, however, it is evident that extreme degrees of both residual radial tilt and shortening will tend to increase the amount of radial deviation and decrease ulnar deviation at the wrist joint.

COMPLICATIONS

Among the unwelcome complications of Colles' fractures are stiff fingers and arthritis of the wrist joint. The wrist joint suffers injury when the distal radial articular surface is fractured. This occurred in 88 per cent. of our cases (Groups II and III). The functional hazard of this injury lies in the development of traumatic arthritis if the articular damage

is not accurately reduced. Roentgenographic evidence of arthritis in the follow-up films was present in a total of 22 per cent. of the cases. Arthritis did not develop in any of seven cases of simple Colles' fracture with no involvement of the radial articular surface (Group I). Of twenty-seven cases of comminuted Colles' fracture in which the fragments of the radial articular surface were not displaced (Group II), arthritis developed in three, or 11 per cent. Of twenty-six cases of comminuted Colles' fracture in which the fragments of the radial articular surface were displaced (Group III), arthritis developed in ten cases, or 40 per cent. At the end of the follow-up period none of the patients with excellent end results showed any arthritis, whereas in 14 per cent. of the cases with good, and in 41 per cent. of those with fair results, traumatic arthritis of the wrist joint developed in consequence of the Colles' fracture.

The ultimate development of traumatic arthritis is largely determined by the amount of bone damage incurred at the time of injury. In a great many cases, however, this complication can be avoided by accurate reduction and efficient immobilization. Thus, if traumatic arthritis does develop, it can result only from one of the following causes, or a combination of them: severe trauma to the distal radial articular surface, inadequate reduction, or inefficient immobilization.

Residual finger stiffness in varying degree was present in 18 per cent. of our cases at the follow-up examination and was due in every instance to faulty application of the cast. This stiffness, it will be remembered, was found on the follow-up examination, made on the average eighteen months after fracture. This is an extremely high toll to pay for a careless error, and emphasizes again the fundamental rule that the cast must stop proximal to the metacarpal heads on the dorsal surface and at the distal flexion crease on the volar surface.

CONCLUSIONS

It has been shown that the type of Colles' fracture incurred bears a definite relationship to the end result obtained. A fairly high percentage of unsatisfactory end results was found in the two groups with comminuted fractures. In addition, in a comminuted Colles' fracture the threat of traumatic arthritis is always present. The basic nature of the fracture must therefore be considered a factor in the prognosis.

The study of the fracture components themselves has demonstrated that the original reduction in all cases has been inadequate. The importance of this factor in influencing end results is illustrated by the fact that those cases showing the most complete reductions have been listed among the excellent end results. Among the fracture components, residual dorsal tilt has a more direct influence on an unfavorable end result than either residual radial deviation, residual shortening, or loss of integrity of the distal radio-ulnar joint.

The method of immobilization used in this series was inefficient and inadequate. Sixty per cent. of our cases, when re-examined eighteen months after injury, showed a fracture healed in a position typical of a fresh unreduced Colles' fracture.

In spite of incomplete reduction and inadequate immobilization the functional results at the time of the follow-up examination were found to be surprisingly good. Satisfactory functional end results were obtained in 68.3 per cent. of cases in this series. The chief credit for this percentage must be given to the innate ability of the wrist joint to overcome and compensate for residual bony deformity, rather than to the original treatment. Studies of function have shown that a great deal of bony deformity must be present before any of the motions at the wrist are compromised. A total of 31.7 per cent. of unsatisfactory results, however, is much too high for a fracture which continues to be lightly regarded and for which treatment tends to follow a routine pattern. The fruits of this attitude are apparent when the entire course of the fracture is reviewed.

We believe that, aside from the specific type of fracture incurred, insufficient reduc-

tion and present inadequate methods of immobilization are the factors responsible for unsatisfactory functional end results in the healed Colles' fractures in this series.

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AN ANOMALOUS TARSAL BONE

BY ALLAN B. HIRSCHTICK, M.D., CHICAGO, ILLINOIS

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The accessory tarsal bones were so well described by Pfitzner in 1896 and by Dwight in 1907 that few variations have been recorded. In more recent years, Milliken described

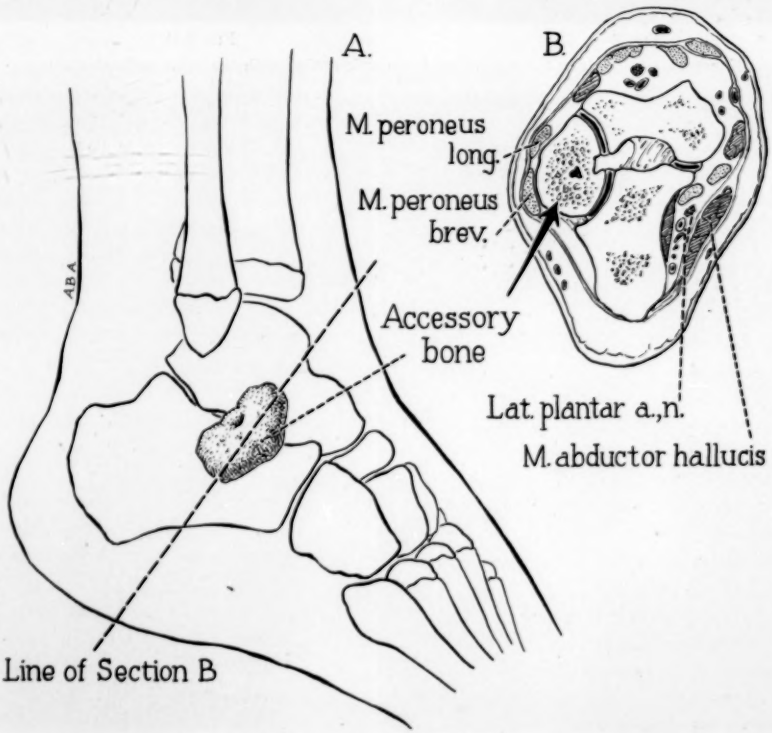

Fig. 1

Drawing showing the location and size of the anomalous tarsal bone.

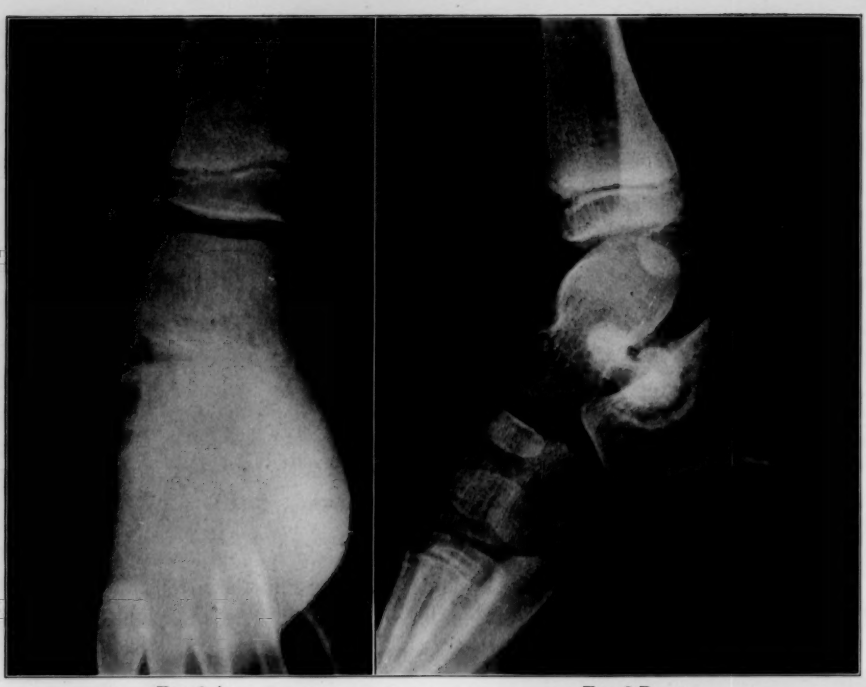

FIG. 2-A FIG. 2-B

Roentgenograms show the anomalous bone articulating with the talus and calcaneus.

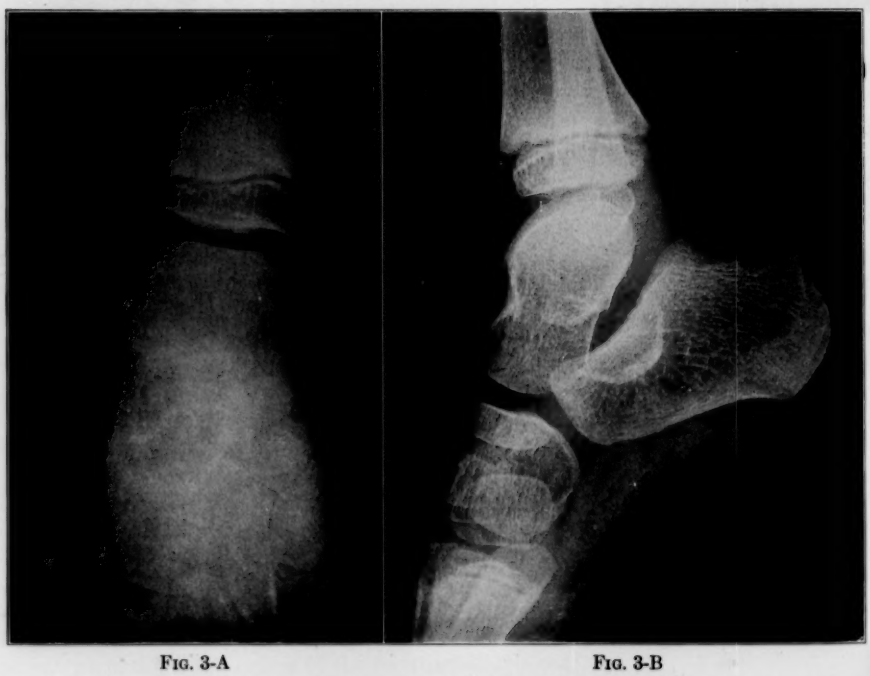

FIG. 3-A FIG. 3-B

Postoperative roentgenograms show defects in talus and calcaneus.

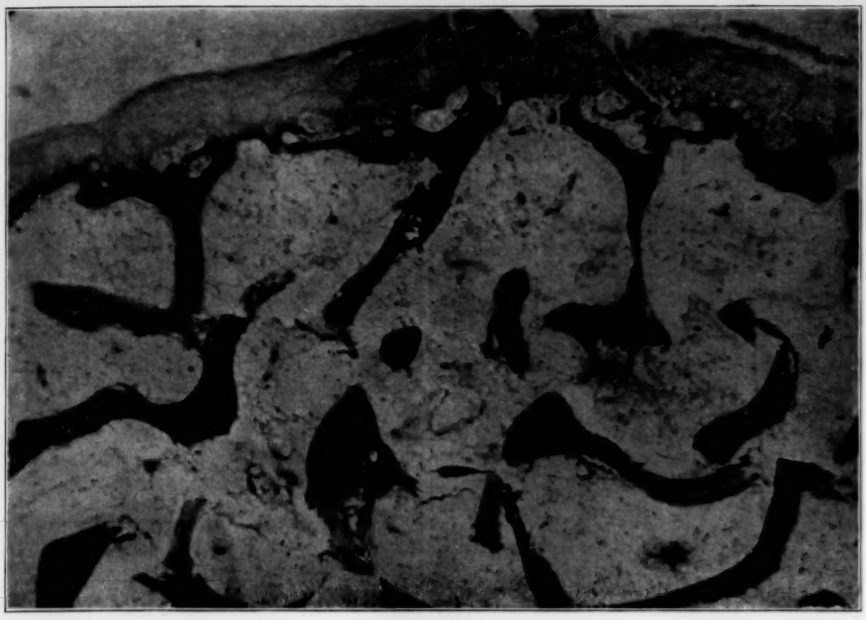

FIG. 4-A

Photomicrograph of specimen (low power).

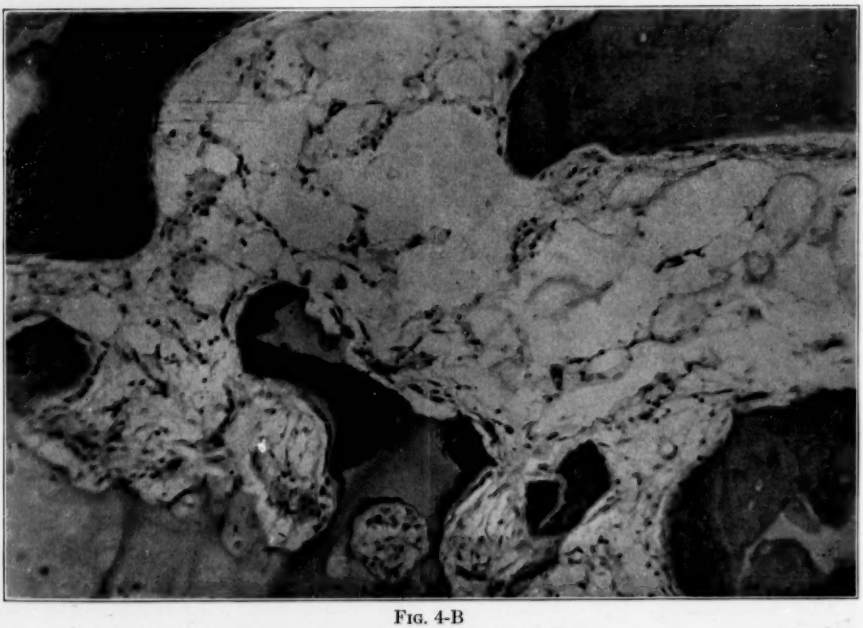

FIG. 4-B

Photomicrograph of specimen (high power).

an os subcalcis, and Burman and Sinberg reported an anomalous talocalcaneal articulation. Marti, in 1947, published a detailed volume on the variations in the skeleton of the

foot and included in it a comprehensive bibliography. In no instance, however, was there described any anomaly resembling that in the case to be reported.

The patient, a five-year-old white boy, was first seen on February 20, 1950. His mother stated that for the previous three weeks she had noticed the boy's right foot turning in when he walked. There was no pain nor was there a limp seen at any time. On examination of the foot, there was noted a hard rounded mass distal and anterior to the tip of the lateral malleolus. This mass appeared to be fixed to the underlying bone. There was no tenderness, and the overlying skin was not adherent. Roentgenograms (Figs. 2-A and 2-B) revealed a large osseous body on the lateral aspects of the talus and calcaneus, with evidence of pressure defects on both of these bones. The left foot was normal.

On February 28, 1950, surgical removal of the bony mass was done. The proximal end of the bone formed a shallow articulation with the talus just above, and anterior to, the lateral tubercle (Figs. 3-A and 3-B). The concavity in the talus was roughly circular, measuring seven millimeters in diameter and approximately three millimeters in depth. From this joint, the anomalous bone curved downward and backward, forming a rough semicircle and articulating with the calcaneus just below and behind the sinus tarsi. The defect in the calcaneus was oval in shape and measured fourteen millimeters across at its widest portion and nine millimeters across at its narrowest part. The defect was approximately five millimeters deep. The anomalous tarsal bone itself resembled in shape half of an elongated doughnut with a small hole in the center. It measured twenty-one millimeters long, twelve millimeters wide, and ten millimeters thick. The distal third of the bone which articulated with the calcaneus was substantially thicker and wider than was the proximal portion.

Gross and microscopic examination of this bony mass revealed it to be composed of normal osseous and cartilaginous tissues (Figs. 4-A and 4-B).

Because of the location of this anomalous bone, the name "os talocalcaneus" is suggested.

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THE SKULL IN PAGET'S DISEASE *

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HISTORICAL BACKGROUND

In 1876 Sir James Paget [33] presented five cases of a more or less generalized skeletal disease which he designated as "osteitis deformans"; by 1889 he had observed twenty-three patients presenting this disorder [35]. In regard to the changes in the skull he particularly stressed "the enlarged cranium, square-looking or bossed" [34], so that this became a diagnostic criterion of the disease. In fact, many later observers were reluctant to accept a diagnosis of Paget's disease unless the skull exhibited these changes, even though Paget himself had reported on several cases in which there was no cranial involvement. Later it came to be recognized that the cranial, and particularly calvarial, changes already noted by Paget in some of his cases were represented by thickening and a cotton-wool appearance in the roentgenogram. These changes occur late in the disease, however, and for a long time little was known about the pathology or the roentgenographic aspects of the early or less advanced stages of the calvarial involvement.

Moore, in 1923, noted that in certain cases of Paget's disease radiolucent areas may be observed in the calvarium, although at that time it was apparently not clear to him that these were a characteristic feature of the disease. Schüller [42], in 1926, introduced the term, "circumscribed osteoporosis of the skull" to describe these radiolucent areas. Sosman, in 1927, demonstrated that an area of circumscribed calvarial osteoporosis actually exhibited the histopathological changes associated with Paget's disease in other skeletal sites. To explain certain discrepancies he advanced the idea that in Paget's disease the pathological process consisted of two phases—an absorptive and a productive phase. Specifically, he suggested that osteoporosis circumscripta might be "the absorptive or destructive phase of Paget's disease at work, with the productive phase held in abeyance". In 1929 Schüller [43] reported on three new cases of osteoporosis circumscripta and reviewed the two cases which he had previously described. He stated that osteoporosis circumscripta might be a bone disease similar to Paget's disease or to osteomalacia, or perhaps a mild form of these diseases.

The problem of osteoporosis circumscripta aroused increasing interest. Weiss [53], in 1930, described two cases of advanced skeletal Paget's disease which exhibited osteoporosis circumscripta of the skull. In the same year [54] he presented a third case which exhibited osteoporosis circumscripta of the frontal and parietal bones, while the occipital region had the typically studded cotton-wool appearance of advanced Paget's disease. Weiss concluded that osteoporosis circumscripta was a rare manifestation of Paget's disease which might persist independently for many years. In 1930 Meyer-Borstel also recorded three cases of osteoporosis circumscripta associated with advanced skeletal Paget's disease. It was his opinion that the incidence of osteoporosis circumscripta was greater than had been generally believed. In 1932 Kasabach and Dyke described the transition, in each of three patients (Cases I, V, and VI), from osteoporosis circumscripta to the typical cotton-wool appearance of the Pagetic skull over a period of eight, three, and two and one-half years respectively. They concluded that "osteoporosis circumscripta and osteitis deformans are one and the same disease". In 1937, Kasabach and Gutman reviewed the literature and reported on fifteen new cases of osteoporosis circumscripta. They believed that "osteoporosis circumscripta is not an obligatory early phase of Paget's disease, but

* Based on a scientific exhibit presented at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N. Y., February, 1950.

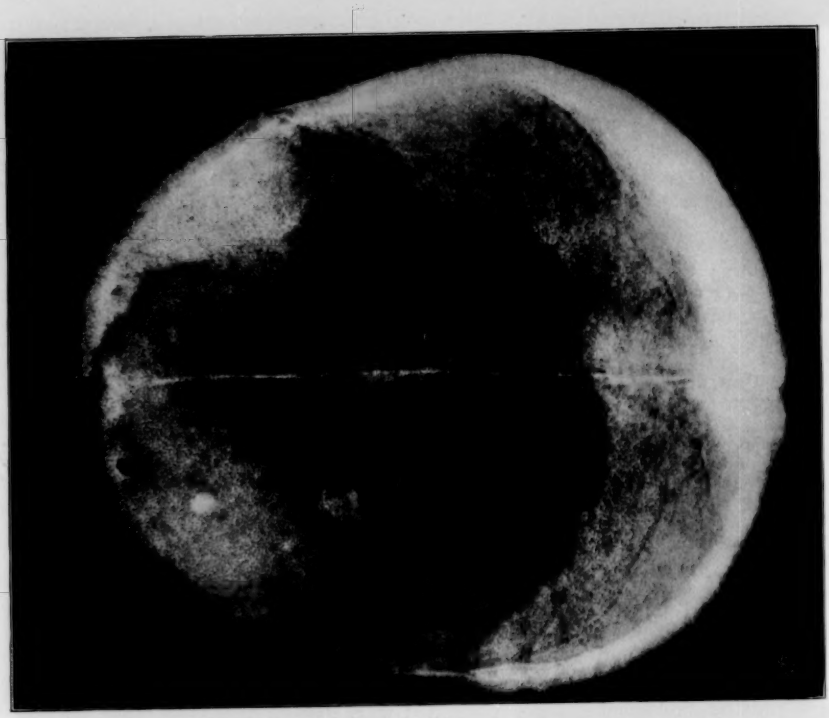

FIG. 2

Osteoporosis circumscripta. Roentgenogram of autopsy specimen, showing large radiolucent area of involvement. Note the vascular channels within the lesion.

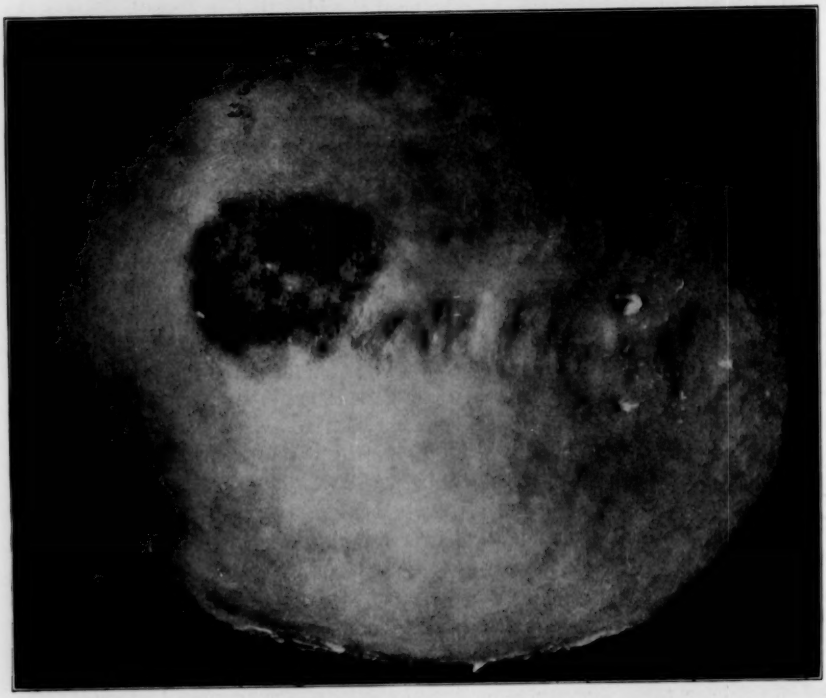

FIG. 1

Osteoporosis circumscripta. Photograph of autopsy specimen, showing the discoloration of the lesion.

a precursor of Paget's disease or, in a broad sense, an atypical form of Paget's disease, as suggested by Sosman".

A review of the foreign literature discloses additional case reports [2,9,12,26,38,50,57]. Three of these publications recorded instances of osteoporosis circumscripta without associated skeletal Paget's disease [12,38,57]. However, the exhaustive study by Erdheim of the basic pathology of osteoporosis circumscripta cranii definitely established the latter as an early phase in the evolution of Paget's disease in the calvarium.

INCIDENCE

Paget's disease does not appear to have any specific geographical or ethnic distribution. In general it is certainly one of the more common skeletal disorders, if one includes cases with local as well as those with generalized skeletal involvement. In many cases with localized involvement, the disease may not be known to be present clinically and is actually restricted to such bones as one or a few lumbar vertebrae, part of the sacrum or of the innominate bone, sometimes even to part of the calvarium, or to several of these areas in combination. Osteoporosis circumscripta of the calvarium may be found alone or in combination with involvement of some other bone. Its true incidence has never been established, but it is by no means an uncommon finding. The pathologist not infrequently encounters it as an incidental finding if the calvarium is removed at autopsy for examination of the brain.

It is widely recognized, as pointed out by Jaffe [19], that the great majority of patients with Paget's disease, irrespective of the extent of its spread over the skeleton, are middle-aged or elderly. Some patients, though relatively few, are under forty years of age, and in some of these cases the disease is already of several years' standing at the time of diagnosis. The writer has seen a patient aged thirty-three in whom the first sign of the disease had been a pathological fracture of the femur at the age of twenty-eight. There have been some reports of Paget's disease occurring in patients in their teens. However, most of these instances apparently represent mistaken diagnoses, although Wagner has recently described what appears to be a well verified case in an eighteen-year-old male.

Kasabach and Gutman investigated the age incidence in forty-six cases of osteoporosis circumscripta cranii. They concluded that, while the general age distribution in osteoporosis circumscripta was the same as that in Paget's disease, the peak age incidence in the former apparently falls two decades earlier. The material on calvarial osteoporosis circumscripta from The Hospital for Joint Diseases does not seem to bear out this age distribution, although it must be borne in mind that the Erdheim collection, from which most of this material is derived, happens to include specimens of many older people.

GROSS PATHOLOGY OF THE SKULL IN OSTEOPOROSIS CIRCUMSCRIPTA

The writer's own investigation is based upon six cases of osteoporosis circumscripta studied at The Hospital for Joint Diseases.

The deep red-violet color of the area of osteoporosis circumscripta cranii stands out sharply from the normal bone. The contrast is due to the fact that the tables are thinned, so that they permit the reddish color of the vascular marrow to shine through. In addition, the vascular channels are increased both in size and in number (Fig. 2), and this increase is frequently associated with great vascularity, which at times is severe enough to suggest venous thrombosis as the underlying pathological condition. Schellenberg has described the ease with which he was able to express an abundant amount of bloody fluid with a vise, to demonstrate the increased blood content of the affected bone. Schmorl [39,40] observed seven cases in which the hemorrhagic discoloration was so pronounced as to suggest hemorrhagic infarction. The porotic area is permeated from side to side by a vascular connective tissue. The roentgenographic picture may be accounted for by the presence of areas of local resorption associated with increased vascularity.

FIG. 3

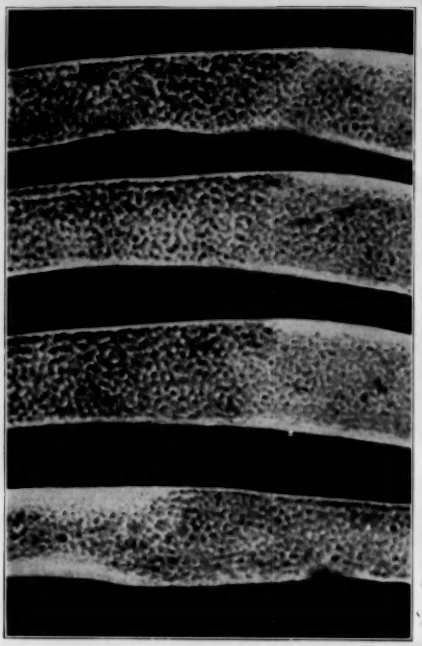

FIG. 4

Fig. 3: Osteoporosis circumscripta. Photograph of a wedge from macerated specimen, showing porosity of the outer table.

Fig. 4. Osteoporosis circumscripta. Roentgenogram of slices from the calvarium, showing the thinned tables and wide-meshed diploic bone.

Despite the changes in structure of the bone in the affected area, the total thickness of the skull remains essentially unchanged. However, such osseous tissue as is present in the area of osteoporosis circumscripta already presents the histological appearance of Pagetic bone.

The earliest gross evidence of osteoporosis circumscripta demonstrable by roentgenographic examination of the autopsy specimens is the presence of an oval area of rarefaction, about 0.25 centimeter in diameter, situated at the terminal portion of a cranial vascular channel. This area expands and subsequently becomes fused with a small, adjacent, similarly rarefied area. The confluent area increases in size. The rate at which osteoporosis circumscripta expands varies from case to case. The rate of expansion was followed by Kasabach and Gutman in roentgenograms made at yearly intervals. In some cases a major portion of the calvarium was involved within three to four years, while in a few instances the lesion did not progress during a five-year period of observation. In two of the cases the lesion appeared to be receding. Calvarial osteoporosis circumscripta may be present while at the same time other skeletal areas exhibit roentgenographic features typical of the disease. On the other hand, calvarial osteoporosis may be discovered and antedate, sometimes by as much as eight years, the appearance of changes associated with Paget's disease elsewhere. The cranial suture lines do not inhibit the spread of the osteoporotic lesion.

The frontal area is the most common site of osteoporosis circumscripta. The membranous bones of the skull appear to be particularly susceptible to the condition. The borders of the affected area are sharply demarcated from normal bone except at the base, where the involved bone seems gradually to merge with normal bone. Because of the

contrasting densities in this region, visualization is usually unsatisfactory and the bone may actually be involved even when it appears to have been spared.

GROSS PATHOLOGY OF THE SKULL IN PAGET'S DISEASE

As the area of osteoporosis circumscripta blends into the more typical lesions of Paget's disease, the violet-red color fades and eventually disappears, yielding to the typical grayish or whitish appearance of the thickened skull. As the vascularity wanes, a process of new-bone formation begins in both tables; this bone rapidly becomes diseased.

In advanced cases the cranium presents considerable alteration in structure. The changes manifest themselves principally in the calvarium, in which involvement is frequently diffuse; the degree of thickening, however, may be irregular. As a rule the thickening of the calvarium is most pronounced in the occipital region. The excessive proliferation of bone found in many cases of Paget's disease is merely an exaggeration of a process found in the average case. The circumference of the skull may increase considerably; in Paget's first patient it enlarged from 56.25 to 69.21 centimeters. In the majority of cases the increase in the size of the calvarium takes place outwardly, and the thickening is the result of the deposition of parallel, fine-fibered layers of bone on the outer table. The new bone is transformed into Pagetic bone, and the suture lines are obliterated.

Knaggs states that, as vascularity declines, the cranial bones go through a stage of advancing sclerosis and the outer and inner surfaces become walled off by condensed bone of varying thickness. The intervening portion shows various degrees of porous, cavernous or cancellous tissue, the spaces of which are filled with a soft reddish structure. Boyd has described the porous nature of the bone by saying that water poured into the thickened skull cap escapes as through a sieve. At the same time that new bone is being deposited, one or more small, oval and patchy foci of sclerosis appear within the area of rarefaction (Figs. 5-A and 5-B). These discrete sclerotic foci become condensed, multiply in number, and eventually produce the cotton-wool appearance characteristic of advanced calvarial Paget's disease (Fig. 6). The foci of sclerosis are seen within the thickened calvarium as islets of eburnated bone, surrounded by a narrow zone of demarcation. Pagetic bone has the appearance of pumice stone, and this is characteristically seen in the skull.

In some cases of advanced Paget's disease of the calvarium the bone may appear normal, but in a fair proportion it is obviously involved. The meningeal-vessel channels are deep and the pituitary fossa may be found altered in consequence. The margins of the neural foramina and the foramen magnum may also become distorted.

Since the facial bones in Paget's disease rarely show pathological changes the face appears abnormally small in contrast to the calvarium. It is not known why the facial bones so frequently escape involvement. It is possible that a routine miscroscopic examination may reveal slight abnormalities in these bones as well. In the rare instances of Pagetic involvement of the facial bones the condition may resemble leontiasis ossea. In such cases the differential diagnosis may be established by the fact that the bones of the lower jaw are the ones usually involved in Paget's disease. Leontiasis ossea, in which the hyperostosis is restricted to the facial bones, has been regarded by some authors as a form of Paget's disease in which the condition is confined to the bones of the skull [14]. Jaffe [19], however, has pointed out that the skull bones in cases of leontiasis ossea "are exceedingly heavy compared with the hypertrophied skull bones in Paget's disease". Another significant point of differentiation can be found in the age of the patients. In 80 per cent. of the thirty-five cases of leontiasis ossea reported by Reiss the disease had started before the twentieth year.

HISTOLOGICAL CHARACTERISTICS

The pathological-anatomical studies by Schmorl [39] in 1932 furthered the recognition of Paget's disease as a separate disease entity and emphasized histologically the jigsaw

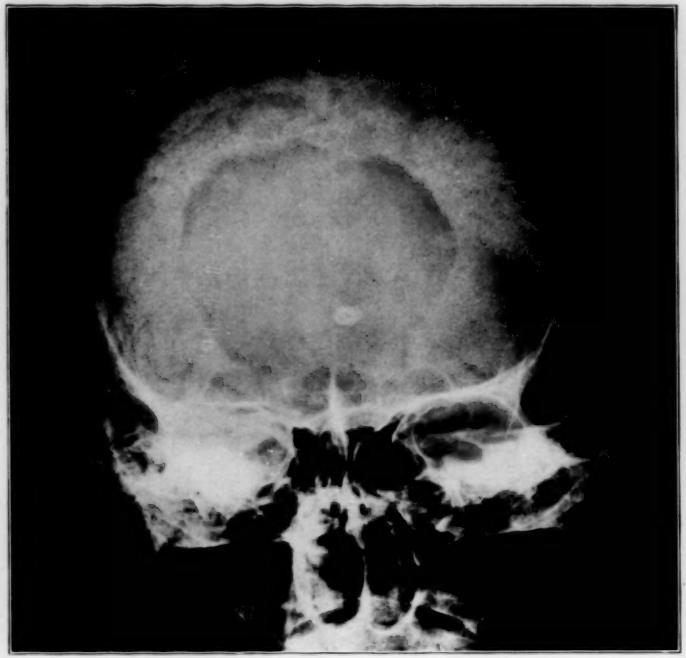

FIG. 5-A

FIG. 5-B

Osteoporosis circumscripta. Anteroposterior and lateral roentgenograms, showing the rarefied lesion in the frontal bone, with patches of sclerosis.

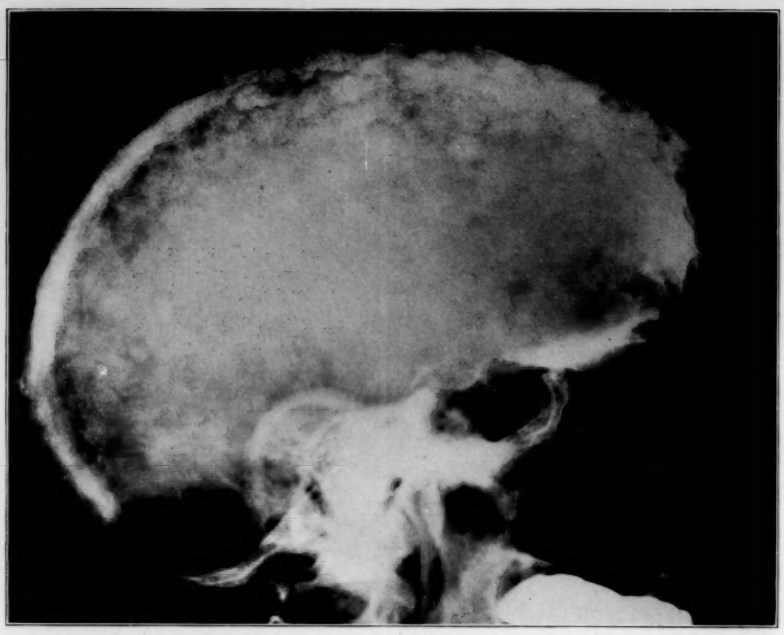

FIG. 6

Advanced Paget's disease. Roentgenogram showing typical cotton-wool appearance of skull.

mosaic bone pattern found in the disease. Knaggs also commented on the histological aspects of the pathological picture in Paget's disease and pointed out "the frequency with which the trabeculae are seen to be decorated with internal curvilinear markings". According to Jaffe [19], encroaching resorption leaves so-called resorption lines in its wake, which become apparent as cement lines when new-bone lamellae are apposed. These distorted cement lines, together with the intervening bone fragments, create the mosaic pattern. Mosaic formations are not encountered in conditions other than Paget's disease with any degree of regularity or frequency. Furthermore, when the mosaic patterns appear in other conditions, their extent is limited and the cement lines tend to be more regular.

Erdheim has given a detailed description of the histological changes in osteoporosis circumscripta cranii. The earliest finding was a marked increase in the cellular elements of the bone marrow, associated with the appearance of cells which resembled lymphocytes. There was increased vascularity, which was associated with a number of small hemorrhages. The second stage occurred in the osseous tissue. The osseous changes began near the border of the lesion in the form of osteoclastic breakdown and resorption. This was followed by an osteoblastic change which resulted in thickening of the diploë. The third stage occurred near the center of the lesion and consisted of a transformation of the bone marrow into connective tissue. This began with oedema and was followed by an increase in the number of fibers until the entire marrow cavity was filled with coarse fibrous marrow.

It is noteworthy that the bone arising from connective tissue in Paget's disease does not show the mosaic pattern. Paget's disease manifests a natural tendency toward spontaneous healing, and histological examination frequently yields evidence of the healing process. This process may be observed in different bones of the same subject and even in different parts of the same bone. Healing is associated with an attempt to reconstruct a

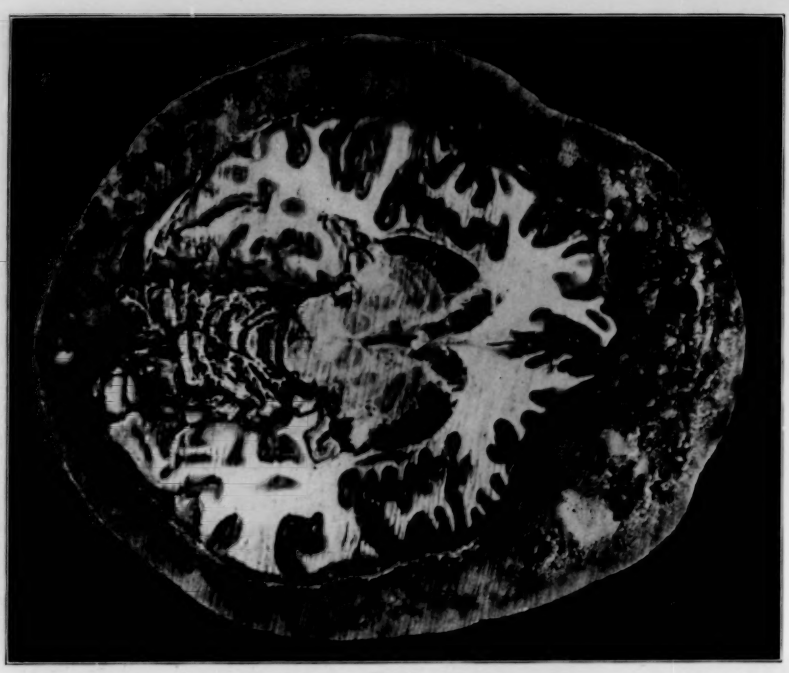

FIG. 7

Advanced Paget's disease. Photograph of autopsy specimen, showing extreme thickening of calvarium and compression of brain.

more compact bone. As a result, lamellar bone formation on a more normal basis appears on the walls of the enlarged vessel canals. The vessel spaces become lined with osteoblasts, and lymphoid marrow reappears in these spaces. This is especially evident in the diploic spaces of the skull. Jaffe [19] has described the histological criteria for the diagnosis of the healing process, noting in particular that the architecture becomes less chaotic, the cement lines become thinner and more regular, and the inclusion masses disappear.

ROENTGENOGRAPHIC CHARACTERISTICS

The roentgenographic features of Paget's disease depend upon the underlying pathological processes of bone destruction and bone repair. Roentgenographic examinations are of the greatest importance, since, in the absence of pertinent clinical findings, they may reveal instances of osteoporosis circumscripta with involvement of the calvarium at an early stage. In such cases the roentgenogram may show a large area of rarefaction in both the anteroposterior and lateral views of the skull.

A frequent characteristic of the Pagetic skull is that, while the outer table is porotic, the inner table is sclerotic. This is seen even on the dentate surface of such enormously thickened cranial vaults as Paget himself demonstrated in 1876. It is well known that porosis of the outer table is a phase of Paget's disease, but the inner table has been incorrectly designated as a normal inner plate. It has been stated that the outer table and the diploë are primarily and most severely affected, while the inner table shows little if any change [21,22]. Actually, this is not true in Paget's disease, where the entire thickened calvarium shows involvement.

The roentgenologist must be on guard against confusing the rarefaction of osteoporosis circumscripta with the rarefied areas of bone destruction caused by tumors seen in the thickened and sclerotic calvarium of a Pagetic skull.

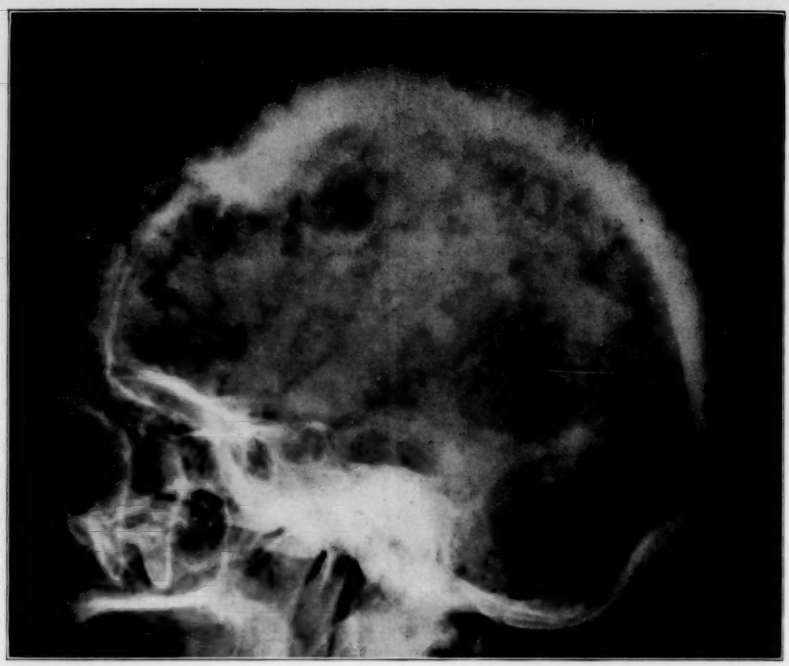

FIG. 8

Advanced Paget's disease. Roentgenogram of skull. The radiolucent areas are the site of giant-cell tumor.

PHOSPHATASE VALUES IN PAGET'S DISEASE

In Paget's disease the serum-calcium and phosphorus values are nearly always within normal limits, while the phosphatase value is invariably elevated. In early cases of monostotic Paget's disease, the elevation may be only slight. In patients with active, widespread Paget's disease exhibiting rapid formation of new bone and increased osteoblastic activity, the serum phosphatase may be as high as 200 Bodansky units, and is quite likely to be around 100 units. The elevated phosphatase noted in cases of osteoporosis circumscripta associated with Paget's disease is due to such foci of sclerosis as may be present, and not to the osteoporosis circumscripta in itself [13].

CLINICAL SIGNS AND SYMPTOMS IN OSTEOPOROSIS CIRCUMSCRIPTA

A review of the literature fails to disclose a single instance of osteoporosis circumscripta cranii which was diagnosed clinically. Clinical signs were absent in all patients. Since the total thickness of the skull in osteoporosis circumscripta remains essentially unchanged, the majority of patients were asymptomatic. For instance, headache was not a common complaint.

The paucity of clinical complaints serves to differentiate between the early phase of Paget's disease (osteoporosis circumscripta) and the later stages (with sclerotic foci and thickening of the skull), during which clinical signs and symptoms become more frequent.

CLINICAL SIGNS AND SYMPTOMS IN ADVANCED CALVARIAL PAGET'S DISEASE

General Appearance

In advanced cases of polyostotic Paget's disease the deformities of the spine, femora, and tibiae may result in considerable loss of height. The enlarged head, apparent lengthening of the upper extremities, waddling gait, and bow legs suggest a simian appearance.

Pain

Headache may be present and at times quite severe. There is nothing specific about the pain as a symptom. Obliteration of the nasofrontal ducts [5,17] and of the air spaces of the frontal sinus [5] may result in swelling of the eye and infection of the sinus.

Cranial-Nerve Involvement

Deafness is a frequent complication in Paget's disease. The petrous portion of the temporal bone is a common site of Pagetic involvement. Encroachment of the disease process on the foramen causes a compression of the cochlear nerve and results in deafness. When the cranium is extensively involved, the abnormality may be sufficiently severe to suggest otosclerosis.

Disturbances of other cranial nerves have rarely been reported. Optic atrophy due to compression of the nerve in the optic foramen has been noted [56]. Gregg has pointed out that compression of the cranial nerves may cause neuralgia, paralysis, and disturbances of the special senses.

Mental Disturbances

Mental symptoms in patients with Paget's disease have been described frequently [6,7,16,18,23,31,41,44,47,48,49]. In the majority of these cases, the patients were over fifty years of age, and the mental state was usually that of the senile psychotic type. It is difficult to estimate how much of the mental deterioration can be attributed to the compression of the brain by bony elevations (Fig. 7), and how much to the cerebrovascular degeneration. Wyllie demonstrated that, while the skull in advanced Paget's disease shows an increased anteroposterior diameter, the depth of the cranial cavity is diminished. It is of interest to note that Grünthal's case showed compression of the cerebellum, with partial disappearance of the Purkinje cells.

SARCOMATOUS DEGENERATION IN CALVARIAL PAGET'S DISEASE

About 75 per cent. of all osteogenic sarcomata develop in the age group of ten to twenty-five years. When a lesion evidently representing an osteogenic sarcoma develops in a person of fifty years or more, a complication of unrecognized Paget's disease should be suspected. Among 211 cases of Paget's disease reported in ten articles, there were eleven cases of sarcoma of the skull: Packard, Steele, and Kirkbridge, one case; Bird, two cases; Locke, one case; Jaffe [19], one case; Kirshbaum, one case; Davie and Cooke, one case; Manganiello, Reimann, and Wagner, one case; Warren and Agar, one case; Albee, one case; Wolfe and Black, one case. This represents an incidence of 5.2 per cent. In the same series there were twenty-two cases in which sarcoma was also present in other bones, the total incidence of sarcoma in Paget's disease in this series thus being 15.1 per cent.

An accurate estimate of the frequency of sarcomatous degeneration in Paget's disease presents a difficult problem, since the majority of reported cases have occurred in patients with advanced skeletal involvement, and few instances of Paget's disease without complications are reported. Sarcoma may develop in a small area of involvement to a very limited degree. The sarcoma may develop simultaneously in several foci of Paget's disease. One cannot deny an important causal relationship between Paget's disease and sarcoma. Although the initiating cause of tumor formation is not clear, Jaffe [19] has suggested that "the tremendous proliferative capacity of the tissues involved in polyostotic Paget's disease may of itself be the basic stimulus to tumor formation".

The type of sarcoma present in Paget's disease is not necessarily an osteogenic sarcoma. A fibrosarcoma may develop instead. Both Jaffe [20] and Snapper have described chondrosarcoma forming in Paget's disease. Cases of coexisting multiple myeloma and Paget's disease have been reported [15, 36]. The author recently exhibited illustrations of two cases (Fig. 8) in which a giant-cell tumor without new-bone formation developed in

connection with Paget's disease of the skull. The prognosis seems to be better in these giant-cell tumors than in osteogenic sarcomata. The usual life expectancy after the development of sarcoma is about one year.

SUMMARY

While many cases of osteoporosis circumscripta cranii escape detection, it is evident that the lesion is not as rare as the number of reported cases would imply.

Diagnosis of osteoporosis circumscripta cranii is possible and may be made as much as eight years before the appearance of Paget's disease elsewhere in the skeleton.

NOTE: The author wishes to express his appreciation to Dr. H. L. Jaffe for the opportunity to study and present several cases from The Hospital for Joint Diseases.

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OSTEOPETROSIS

Case Report, Autopsy Findings, and Pathological Interpretation: Failure of Treatment with Vitamin A *

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The disturbance in bone formation known as osteopetrosis has been the subject of considerable study during the last two decades. However, the available autopsy data are contained in fewer than twenty case reports [9,13,17,20], and these include much variation in material and interpretation. The etiology and pathogenesis remain obscure. The present case report, with an extensive autopsy study, is offered as an addition to the anatomical descriptions already published.

CHART I. GROWTH STUDY LEFT TIBIA

	August 1947	December 1947	March 1948	March 1949
Overall length (cm.)	9.8	11.1	11.4	12.0
Distance between epiphyseal cartilages	8.9	9.8	10.3	11.6
Diaphysial length	4.5	5.4	5.7	6.4
Upper metaphysis	1.9	2.2	2.2	2.2
Lower metaphysis	2.4	2.2	2.4	2.9

CASE REPORT

E. K., a girl aged thirty-two months at the time of decease, was observed at The Children's Hospital for the last twenty months of her life. The family history was negative for consanguinity. No known cases of osteopetrosis had occurred in the parents, three siblings, or relatives.

This child was born at full term; gestation and delivery had been normal. Feeding difficulties were present from the beginning. When the patient was six weeks old, a chronic nasal discharge and partial obstruction became evident; later the parents noticed that the eyes behaved abnormally. At four months of age, she was hospitalized in another city, where a diagnosis of osteopetrosis with optic atrophy was made. Until her admission to The Children's Hospital at one year, the child gained weight (from eight to seventeen pounds), but continued to present a chronic upper respiratory infection, with one very severe episode of pneumonia at four months; she was treated with penicillin. The only other treatment subsequently was a daily administration of 25 milligrams of ascorbic acid and 40 drops of viosterol. The patient's first tooth erupted when she was five months old, and by the time she was nine months old four incisors had appeared. No teeth erupted subsequently. Her neuromuscular and mental development was greatly retarded; at one year she was barely able to hold her head up. She could rock on all fours, but was unable to stand or sit.

On admission to The Children's Hospital the patient was found to be well nourished but underdeveloped for her age—that is, in the lower three percentile for weight and height. Her head measured 46.5 centimeters in circumference, and frontal bossing was present. The anterior fontanelle measured 3 by 3 centimeters and

* This study was aided by grants from The Nutrition Foundation and from the Williams-Waterman Fund for the Combat of Dietary Diseases, as well as by a grant from the Playtex Park Research Institute.

FIG. 1

Roentgenogram of lower extremities. The homogeneous increase in density, clubbing, and transverse striation is clearly evident.

was firm and pulsating. The cranial sutures were not closed. The pupils were non-reactile and ocular movements were haphazard. Optic atrophy was evident retinoscopically. The hearing was impaired and the eardrums were thickened. Nasal obstruction was moderately severe and there was a mucoid nasal discharge. Four broad incisor teeth were erupted. Lymph nodes were palpable in the inguinal, axillary, and cervical areas. The chest was normal except for signs of slight cardiac enlargement. The liver and spleen were smooth, enlarged, and palpable 4 centimeters below the costal margin. Slight hyperactivity of normal reflexes was elicited, but there were no pathological reflexes. The skeletal system appeared normal by physical examination.

Laboratory Findings

The red-cell count ranged progressively downward from 3.4 (6 per cent. reticulocytes) to 0.8 million (3 erythroblasts and 19 normoblasts per 100 white blood cells) and the hemoglobin from 12 grams to 2 grams (26 per cent. hematocrit). The white-cell count fluctuated between 29,000 and 8,000. The serum protein remained about 6.3 grams; the non-protein nitrogen varied from 32 to 41 milligrams per 100 cubic centimeters, while the serum calcium varied from 10.5 to 7.4 milligrams per 100 cubic centimeters, the serum phosphorus from 6.1 to 5.6 milligrams and the alkaline phosphatase from 9.6 to 6.8 Bodansky units. The glucose-tolerance test showed a rise to 102 milligrams from 87 milligrams fasting in one hour. The two-hour level was 68, with return to 84 in three hours.

Roentgenographic Findings

The bones presented the typical features of osteopetrosis (Fig. 1), — namely, diffuse increased density of the skeleton, obliteration of the marrow cavity in the long bones, clublike enlargement of the metaphyses of all long bones (diminution of remodeling) and metaphyseal transverse and longitudinal bands. Examination of serial roentgenograms covering the twenty months of observation yielded the following growth data as measured in the left tibia (Chart 1).

Growth proceeded quite regularly as shown by the increase in over-all body length (66 centimeters at twenty months to 77.5 centimeters at thirty-two months). The elongation of the diaphysis proper kept pace with the growth of the tibia, so that the distance between the diaphysis and the epiphyseal cartilage remained nearly constant.

Course

After her infection had been controlled with penicillin, the patient was treated with large doses of vitamin A.* Chart 2 records the dosage and pertinent serum chemical determinations. No detectable change in the bones was seen, even when signs of toxicity (scaly dermatitis, anorexia, fissures on the lips and corners of the mouth) forced discontinuation of medication. Withdrawal of the vitamin-A dosage was followed immediately by cessation of these symptoms. The patient's upper respiratory infection led to a chronic otitis media and the hemogram showed progressive anaemia, while the white-cell count fluctuated with exacerbation of the infection. Her activity and resistance to infection slowly declined, but no change involving the skeleton or viscera could be demonstrated. Shortly before death, when her hemoglobin measured two grams, there was a decrease in platelet count; petechia formation and epistaxis occurred, one episode of which was fatal.

AUTOPSY FINDINGS

External Examination

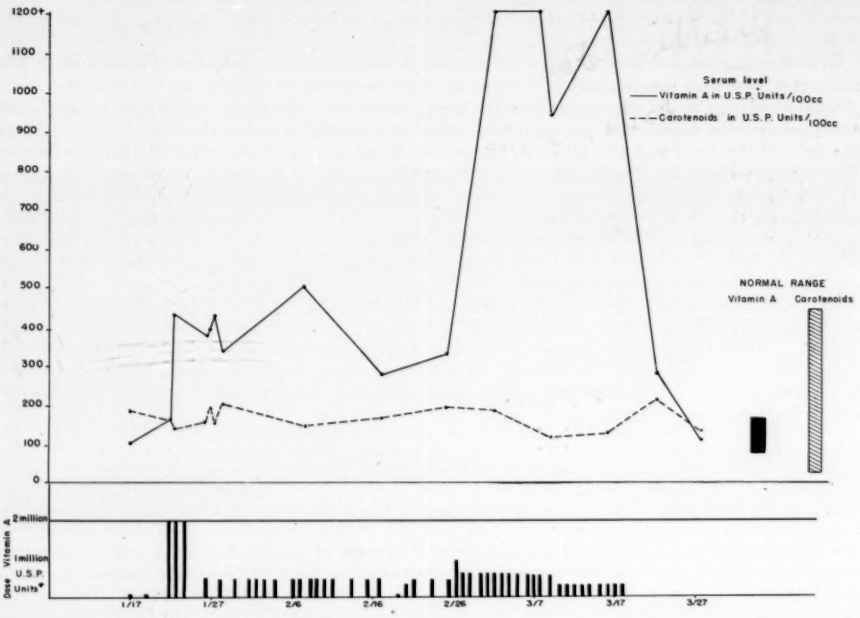
The circumference of the head was 50 centimeters (normal circumference, 50 centimeters); body length 77.5 centimeters (normal body length, 85). The skin was pallid. The anterior fontanelle was firmer than usual and measured 3 by 3 centimeters. The cervical and inguinal lymph nodes were palpable. The ends of the long bones seemed enlarged. Four erupted incisor teeth were present. The liver and spleen were palpably enlarged.

* Vitamin-A concentrate (500,000 units per gram), supplied by Distillation Products Industries, was administered by gavage. One milligram of Vitamin A equals 3,500 U.S.P. units.

Viscera

The brain weighed 950 grams (normal weight, 1120 grams). It was overlaid by a large, fresh subdural hematoma in the right parietal and frontal areas. The consistency of the brain was quite firm; slight diffuse cortical atrophy was evident. Section showed no ventricular enlargement. The spinal cord was normal grossly. The pituitary gland was not enlarged or grossly abnormal. The organs of the neck (pharynx, trachea, oesophagus) were not unusual. The parathyroid glands were four in number and not enlarged. The thyroid and thymus were of normal consistency, size, and shape. No vascular anomalies of the mediastinum were found. The heart weighed 74 grams (normal weight, 60 grams) but showed no valvular or septal anomaly. The musculature was flabby and pale. The lungs contained a few emphysematous blebs; some frothy fluid (terminal oedema) was expressed from the bronchioles. One small area of consolidation was found in the left lower lobe. A moderate amount of clear yellow liquid was contained in the pleural, peritoneal, and pericardial cavities. In the abdominal cavity, the alimentary tract was not remarkable except for a few petechial hemorrhages in the stomach wall. The liver was slightly enlarged, weighing 420 grams (normal weight, 380 grams). Its external configuration and lobular pattern were normal. The spleen was firm and enlarged, weighing 122 grams (normal weight, 35 grams). Its surface was dark and demonstrated increased lymphoid

CHART 2. VITAMIN A STUDIES



markings, but section offered no unusual resistance. The pancreas was grossly normal, as were the kidneys, both externally and on section. The adrenal glands were of the usual size and had normal corticomedullary proportions. The pelvic organs (vagina, uterus, ovaries, fallopian tubes, and bladder) were not unusual except for a few petechial hemorrhages on the peritoneal surface of the bladder. The lymph nodes were enlarged, fleshy, and mottled pink on gray.

Skeletal System

The following bones were examined: skull bones, mandible, vertebrae, ribs, humeri, radii, ulnae, metacarpals, phalanges, femora, tibiae, and fibulae. The details which are recorded are a representative selection of observations on all these bones.

The calvarium (and all other bones equally so) was stony hard, and was sawed through or drilled with difficulty. When bent it proved brittle, and the broken ends were sharp and saw-toothed, without the green-stick appearance common in bones from patients of this age group. All the bones lining the cranial cavity presented slight homogeneous thickening, and the differentiation into tables and simple diploë usually

present at this age was not seen. No distinct lamellae representing tables were discerned grossly. The dura was stripped with difficulty and some gritty marrow-like material was found to adhere to its calvarial surface. All of the foramina were smaller than usual and their edges were rounded, elevated, and smooth. The petrous bone showed some encroachment by bone on the inner and middle ear, the cavities of which were quite small, as if compressed. The structures were not distorted, however, and the ossicles were of the usual size and articulation. The eardrums were thickened, but no exudate was present in the middle ear. No mastoid or antrum cells were present. Moderate thickening of the clinoid processes was present and the pituitary fossa, while of normal size, had a direction more postero-inferior than is usual. No air sinus could be found in those areas of the ethnoid and maxillary regions where these are usually present. The maxilla and mandible showed the same disturbances as the other cranial bones,—that is, an absence of demarcated cortical bone and an intensification of the cancellous network at the expense of marrow space. Their gross outlines were not unusual.

The spine presented no abnormalities of curvature, but individually the vertebrae were composed of two differently colored hard materials. A white, granite-like component in the shape of an hourglass comprised most of the vertebral body, while a reddish, hard bony ring, triangular in cross section, circumscribed the niche in the hourglass (Fig. 2).

The ribs showed broadening and deficient tubulation extending 3 centimeters laterally to the costochondral junction. At this area there was a gritty red material subperiosteally, intervening between the periosteum and the bone beneath. No definite layer of cortical bone could be demonstrated, nor was a marrow cavity visible on section of the rib. The bony portion was white, homogeneous, and ringed by the red subperiosteal material.

All of the long bones showed similar abnormalities, while the adjacent joints were quite normal. The articular cartilages were smooth, and in those areas where secondary ossification centers were absent the epiphyseal cartilage also did not appear unusual. Where secondary ossification centers were present, these centers presented the same white, homogeneous, stony hard material found in the other bones, while the epiphyseal cartilage itself was not thinner or harder than usual, nor was it distorted. The principal abnormality of the shape of the long bones was a tendency toward symmetrical broadening of the ends of the bones. While the central diaphyseal expanse was of normal thickness, the flaring and broadening where the diaphysis merged into the metaphysis occurred much closer to the central portion of the shaft than ordinarily. The flare was more gradual than in the normal metaphysis and persisted as far as the area of the epiphyseal cartilage. Anatomical landmarks such as the lesser trochanter, tibial tuberosity, and other protuberances seemed broader and less elevated than usual.

Section of a few bones in the longitudinal as well as transverse plane was performed. In none of the long bones was a distinct marrow cavity encountered. All of the bones showed, in the narrowed diaphyseal section, an area of reddish sclerotic but cancellous bone which was well demarcated from the white homogeneous material already described. The latter material extended to the epiphyseal cartilage and resembled in shape two elongated cones fitting into the hollow ends of the diaphysis (Fig. 3). Each of these conical masses is termed a *chondro-osseous complex*.

Microscopic Examination

The *heart* showed scattered small foci of erythropoiesis and rarely a myelopoietic focus. Oedema of the myocardium was moderate. The *lungs* showed small areas of atelectasis and emphysema. Occasional areas of inflammation surrounding the bronchioles were seen and frequent hematopoietic foci were also present. Where inflammation was present, fibrosis usually was minimal or absent, but small hemorrhages were encountered frequently. Sections from the consolidated areas showed more diffuse inflammation with microabscess formation. The *spleen* showed scattered Malpighian corpuscles and germinal centers. The sinusoids were congested. Most of the splenic tissue was composed of hematopoietic cells. The *oesophagus*, *stomach* and *intestinal* sections were not remarkable. The *pancreas* had normal islets and acini, interspersed among which were hematopoietic foci. The *liver* showed a normal capsule and normal biliary system and lobular structures. Hematopoietic centers also were frequently seen among the lobules. The *kidneys* also presented hematopoiesis as the principal deviation from normal. Sections of the *adrenal* glands were not remarkable except for a few small cortical adenomata. Sections of the *pelvic organs* (uterus, bladder, ovary, and fallopian tube) were normal. Similarly, sections of the *skin*, *skeletal muscle*, *tongue*, *diaphragm*, *tonsil*, and *thymus* were not unusual. The *parathyroids* were composed almost entirely of stroma and principal cells, with no acidophilic cells. No adenomata were found. The *thyroid* presented small follicles, some containing colloid, some empty. The acinar epithelium was low cuboidal. The *lymph nodes* showed few germinal centers, but much of the tissue seen was hematopoietic, often resembling that of the spleen. The *brain* and *spinal cord*, apart from those sections of the cortex subjacent to the subdural hematoma, were not unusual. No gliosis, degenerative or other changes could be detected. The *pituitary gland* was examined in serial section and no unusual findings were present. Perhaps a minimal increase in the ratio of eosinophils to basophils and chromophils was seen, but the finding was within normal limits. The pars nervosa was normal.

Bones: The microscopic details of the bony structure are best described by referring to the photo-

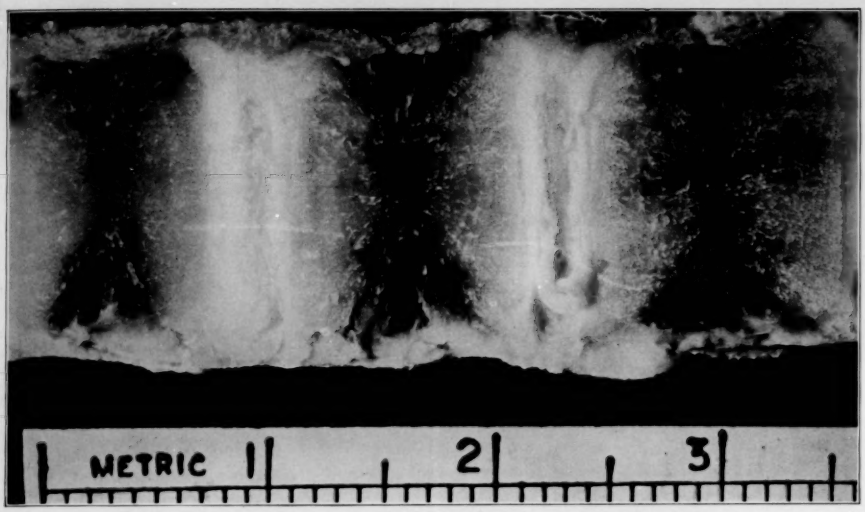


FIG. 2

Three vertebrae sectioned anteroposteriorly. The clefts represent the vascular supply. The chondro-osseous complex, in the shape of an hourglass, is bordered by small amounts of bone in the cleft region.

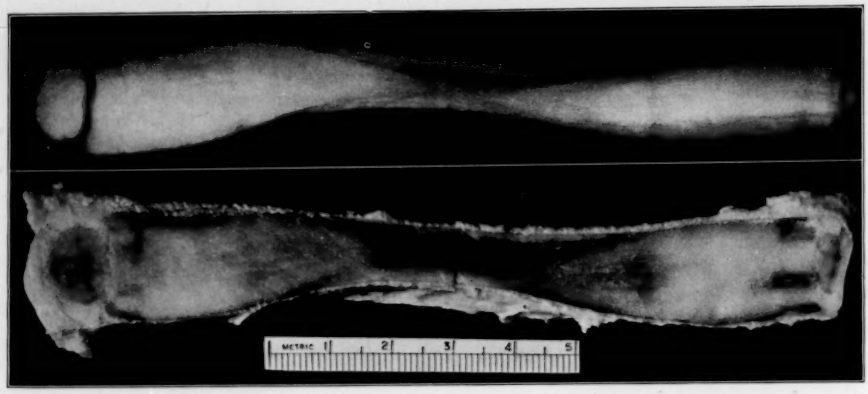


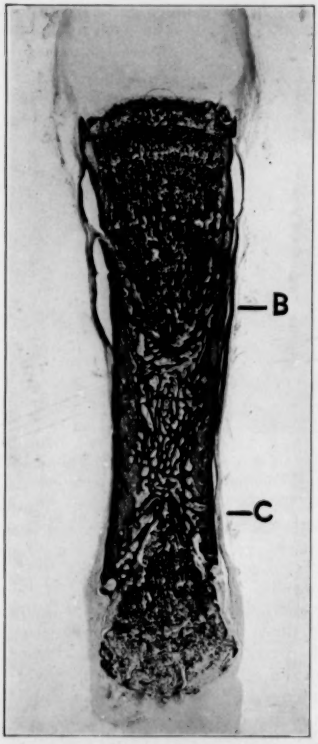
FIG. 3

Tibia sectioned axially. The roentgenogram shows the true length of the diaphysis (6.4 centimeters) with cones of chondro-osseous matrix inset on either end. The photograph shows the vascularity of the cancellous part of the diaphysis. A small subperiosteal hemorrhage at the upper right is related to a metaphyseal transverse and longitudinal fissure fracture.

micrographs. Figure 4-A shows a coronal section through a metacarpal bone. The cartilage from the joint surface to the zone of cytomorphosis of the epiphyseal cartilage (zone of provisional calcification) was found to be normal and the endochondral sequences were within normal limits down to the hypertrophic cartilage cells. As one progressed from these cells toward the shaft, a remarkable persistence of cartilage matrix was encountered. The extent of the length of bone in which the persistence of cartilage matrix occurred corresponded to the area of widening of the metaphysis observed roentgenographically as well as to the cone of white, granite-like material seen grossly. While capillary penetration of the original epiphyseal cartilage proceeded normally, with vascular tufts and osteoblasts adjacent to the diaphyseal end of each column of hypertrophic cells, the trabeculae of cartilage matrix persisted unresorbed for a considerable distance toward the shaft. Nearer the tapering portion of the chondro-osseous complex, however, resorption of the matrix was seen both peripherally and to a lesser degree interstitially. Concomitantly, there was deposition of osteoid as well as of bone on the unresorbed cartilage matrix and, while only small amounts of osteoid and even smaller amounts of bone occurred in the immediate subepiphyseal area, the amount of bone deposition in-

creased regularly as the shaft was approached, while osteoid deposition became more infrequent. In the cone-shaped chondro-osseous segment the intertrabecular spaces, ordinarily wide and full of hematopoietic marrow, were very narrow and filled with a loose fibrous tissue containing sinusoidal vessels, while only occasional foci of hematopoiesis were seen. While the pattern of the chondro-osseous tissue was fairly regular, there were occasional longitudinal streaks of widened intertrabecular spaces filled with fibrous tissue and hematopoietic marrow and containing thin laminae of bone (Figs. 3 and 8). These were responsible for the longitudinal lines of diminished density seen on the roentgenograms. They were present more frequently in the larger long bones. Each longitudinal band was continuous with one of the transverse lines to be described. The structure of the confluent transverse and longitudinal bands was identical. The transverse lines of diminished density evident on the roentgenogram were often seen microscopically without concomitant longitudinal bands. Almost without exception one such transverse line was in the neighborhood of the beginning taper of the chondro-osseous complex, while another was at the junction of epiphyseal cartilage and chondro-osseous complex. While most of these lines extended completely across the entire width of the bone, other lines were incomplete. The depth of the lines varied. The composition of the tissue was mostly fibrous, but small hemorrhages in these areas were not uncommon. Moreover, the trabeculae of cartilage matrix were discontinuous throughout the zone and often were sealed both on the epiphyseal and diaphyseal ends by plaques of bone. Cancellous bone usually occurred in this zone, frequently presenting wide intertrabecular interstices filled with fibrovascular marrow (Figs. 5 and 6). When these zones were traced to the cortex, a hiatus in the cortical lamina was always present. The transverse lines, therefore, may be most readily interpreted as healed fissure fractures, while the longitudinal bands probably represent healing of a longitudinal splintering of the brittle chondro-osseous complex (Figs. 7 and 8).

The bone of the diaphysis (Fig. 9) presented a variable composition which was best demonstrated in a longitudinal section. At the level of the chondro-osseous complex where the first evidence of cortex was encountered, there was a thin lamina of immature bone (fibrous bone) adjoining the complex. Plaques of this immature bone were seen persisting along the outline of the cone, and often the internal portion of these plaques stained more darkly than the external. The plaques were discontinuous and were perforated by bands of fibrovascular tissue; these sometimes merged into the periosteum and sometimes connected with the fibrous tissue of the marrow in the cancellous bone adjoining the chondro-osseous complex. External to the plaque described was a zone of immature cancellous bone with irregularly staining matrix and lacy, woven trabeculation. The further one progressed longitudinally toward the middle portion of the diaphysis or transversely toward the periphery, the more mature this bony matrix and trabeculation became. In none of the bones was the cancellous component resorbed at the center of the shaft with formation of a definitive fatty marrow cavity. The cancellous bone was the site of the greatest volume of hematopoietic tissue, particularly at the central part of the diaphysis, while at its extremities the marrow contained more fibrous elements. On the periphery of the cancellous zone, at the level of the center of the diaphysis, normal compact bone was present and circumferential lamellae also were more clearly demarcated. The thickness of these last two layers varied with the level of the section, being thinner at either end of the diaphysis and becoming progressively thicker as the center was approached. The processes of remodeling in the shaft section were well portrayed in the cement lines and thickness of the circumferential lamellae.



The periosteum frequently showed small areas of hemorrhage and hemosiderin deposition, and occasionally there were areas of hematopoiesis subperiosteally which exceeded in volume the hematopoietic foci within the bone nearby.

Sections of the secondary epiphyseal center of ossification showed the same structure as the chondro-osseous complex already described. There were no plates of bone bordering the epiphyseal

Fig. 4-A: Metacarpal in axial section to demonstrate the general configuration of a long bone. Note absence of marrow cavity and relation of chondro-osseous matrix to cortex. Epiphyseal cartilage is normal. No secondary ossification centers are present.

Figs. 4-B and 4-C are transverse sections of humerus at the levels analogous to those marked *B* and *C* on Fig. 4-A. One factor in the mechanism of remodeling is portrayed in the asymmetrical deposition of bone around these cores.

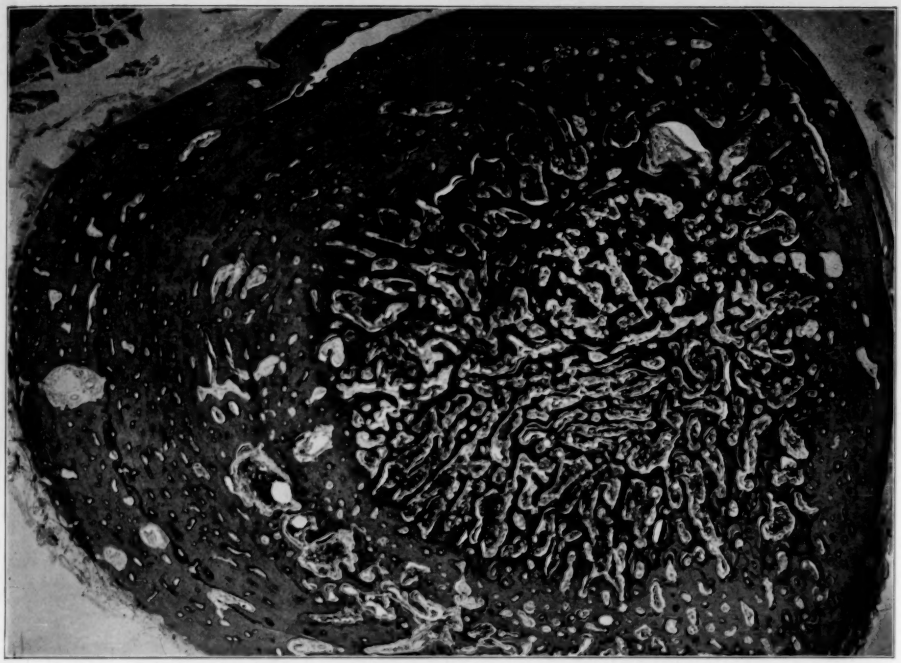


FIG. 4-C

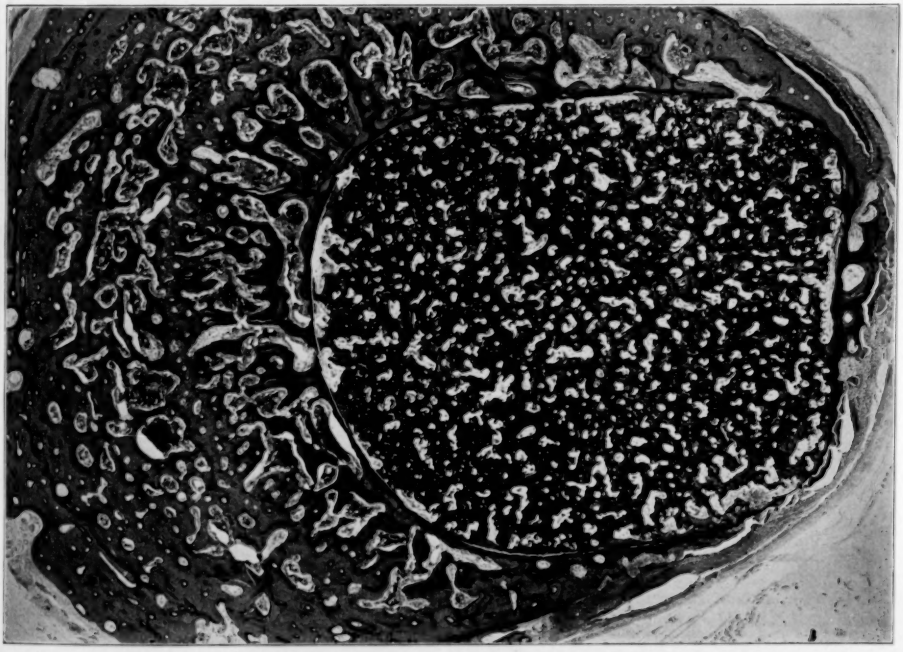


FIG. 4-B

cartilage as would be found in normal bone. The articular cartilage and the vertebral cartilage showed the same endochondral sequences in a much slower and more irregular fashion than was present in the long bones.

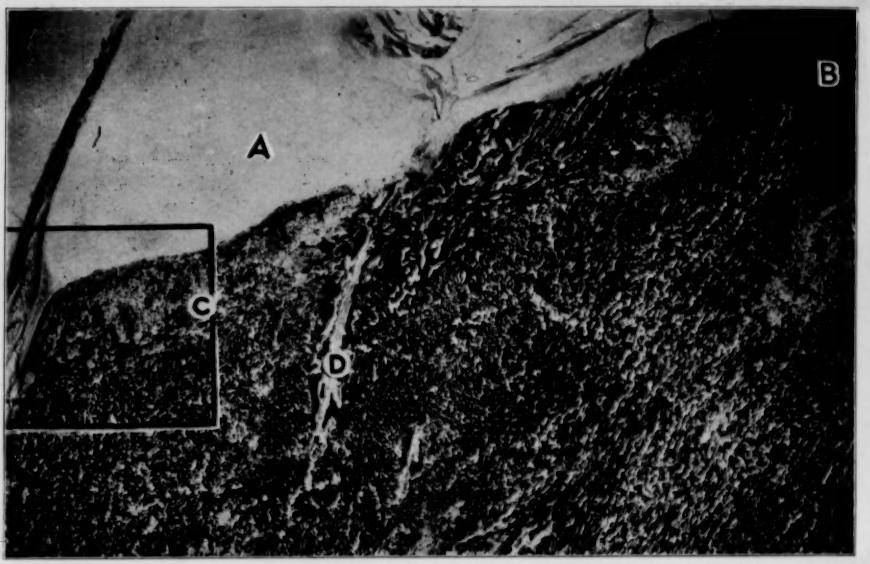


FIG. 5

Head of femur. At upper left (*A*) is the greater trochanter. At upper right (*B*) is the capital epiphysis. The mechanics of healing of fractures is demonstrated at *C* and *D*, which show callus in transverse and longitudinal orientation. No analogous transverse line passes below the femoral head. *C* represents a metaphyseal fracture line below the trochanter.

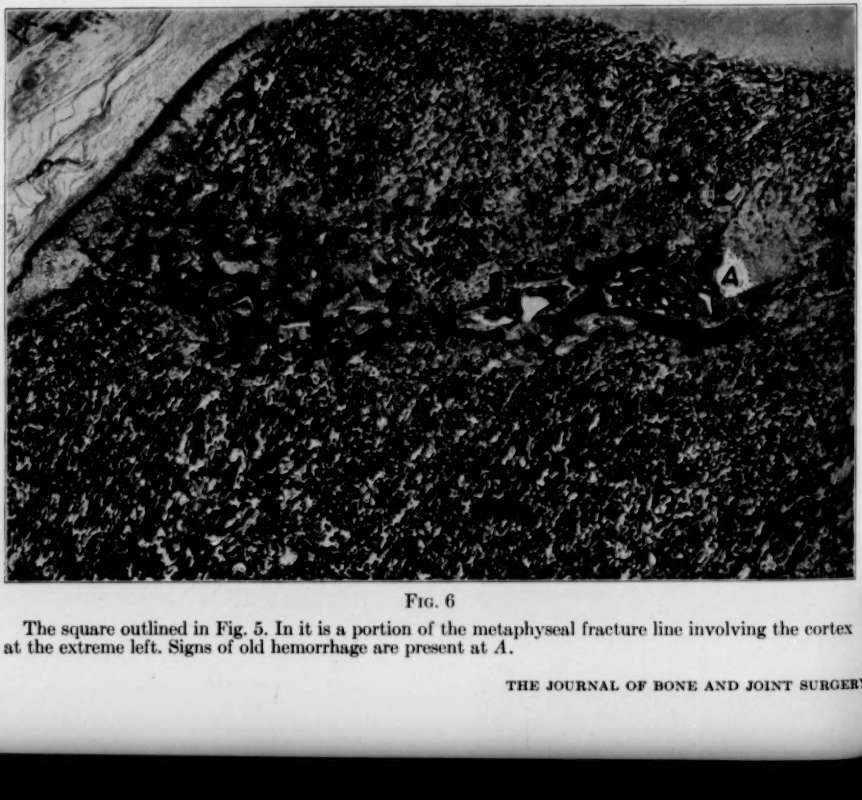


FIG. 6

The square outlined in Fig. 5. In it is a portion of the metaphyseal fracture line involving the cortex at the extreme left. Signs of old hemorrhage are present at *A*.

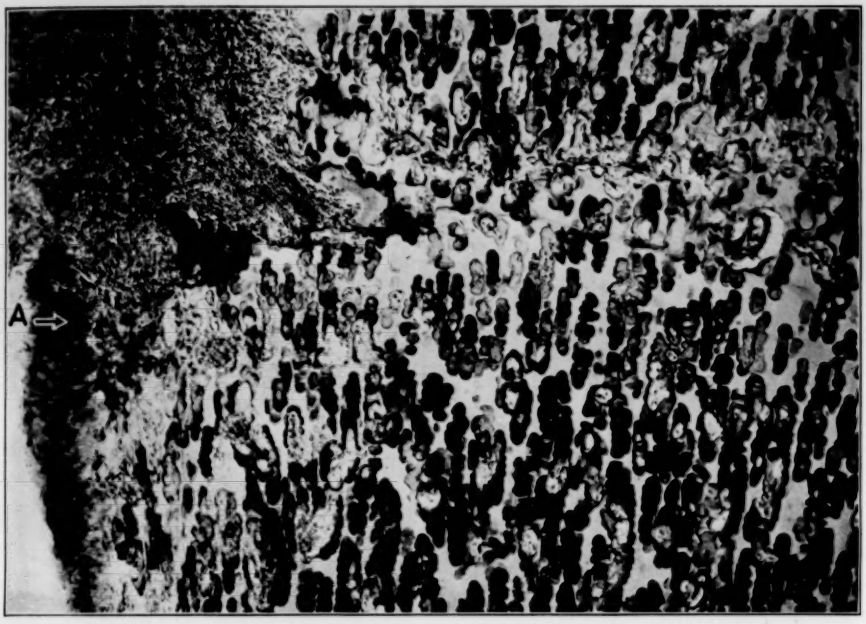


FIG. 7

Fracture, early stage, in a metacarpal just at the extremity of the diaphysis. Cortical bone is represented at *A*, with hemorrhage just above it. The transverse fissure through the chondro-osseous complex is seen adjacent.

The sections of membranous bone (Figs. 10 and 11) that is, of the skull and mandible, revealed disturbances in architecture similar to those in the endochondral bone. Sections from the calvarium showed that, while the outer table subperiosteally was being formed normally in a smooth continuous layer with circumferential lamellae underlaid by compact bone, there were abnormalities of the inner table and especially of the intervening diploë. The extradural bone was characterized by more resorption than is normal, and although most areas showed a thick layer of compact bone and circumferential lamellae, often wide zones could be seen where this layer had been entirely resorbed. However, the most striking deviation from normal structure was seen in the diploë, where there was sturdy trabeculation of cancellous bone throughout. The intertrabecular spaces were narrow and filled either with fibrous tissue or hematopoietic tissue, mostly of the erythropoietic series. Here, as in all other foci of blood formation, the sequences and relative number of immature and mature cells were not unusual. This cancellous bone of the diploë was dense and more closely knit than is found even in the adult and differed markedly from that normal for the patient's age as it consisted of a wide marrow space with an occasional strut holding the tables together. This bone showed the variable staining and structure characteristic of varying periods and rates of deposition, the most immature layer being near the sutures. At all points it merged into the compact bone of the tables, but at some points a cement line separated the two layers. The immature bone was characterized by profuse cellularity, the cells frequently forming a columnar arrangement resembling columns of cartilage. The fibrous elements were prominent and the staining reaction of the matrix was variable. Basophilic, metachromatic, and acidophilic areas all could be discerned (Fig. 11).

The teeth and the jaw sections followed the same general pattern. The teeth were normal histologically with the exception of slight disturbance of calcification in the most recently deposited dentine. This consisted of bluish globules in the region of dentine adjacent to the odontoblasts. Erupted and unerupted teeth were sectioned. Except for a few small hemorrhages within the pulp, all general developmental features were within normal limits. The outer compact bone showed normal Haversian systems and circumferential lamellae. The most striking abnormality was in the cancellous bone composing the central portion of the mandible and forming the tooth socket. Here a structure similar to that described in the calvarium occurred,—namely, interlaced and bony trabeculae with marrow mostly fibrous in character. Barely enough space was present to accommodate nerve and vessels.

Section of the eye showed complete gliosis of the optic nerve. No evidence of regenerative processes

FIG. 9

(See page 933)

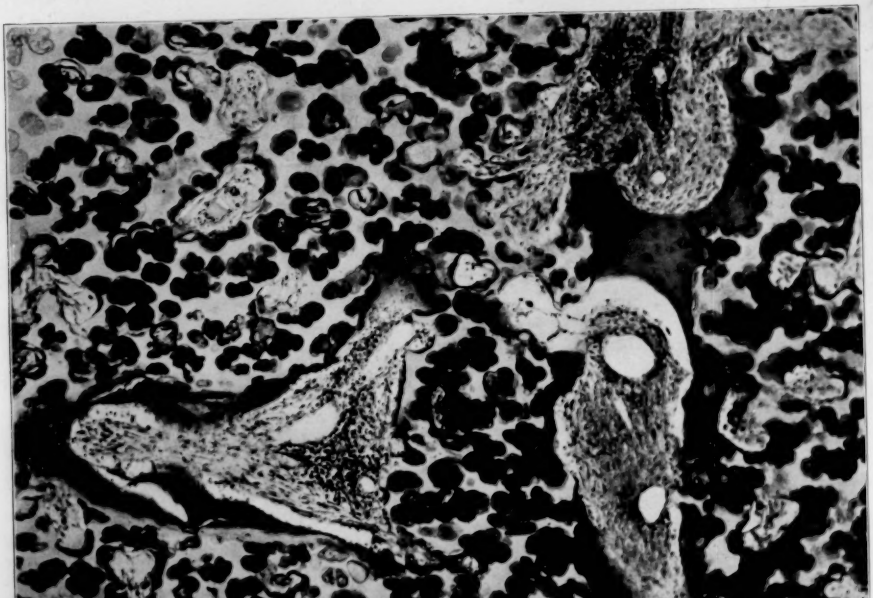


FIG. 8

Fig. 8: Fracture with transverse and longitudinal components. Bony and fibrous repair are evident. Note also the structure of chondro-osseous complex. The bone stains dark and fills many rounded lacunae in the cartilage which stains very light. Patches of fibrous marrow are also evident.

Fig. 9: Longitudinal section of diaphysis of metacarpal. At *A* is the distal end of the chondro-osseous cone. The transition to the cancellous bone of the core of the diaphysis is shown. Note the fibrous marrow. Isolated hematopoietic foci are seen at *B*. The cortical bone is seen on either side.

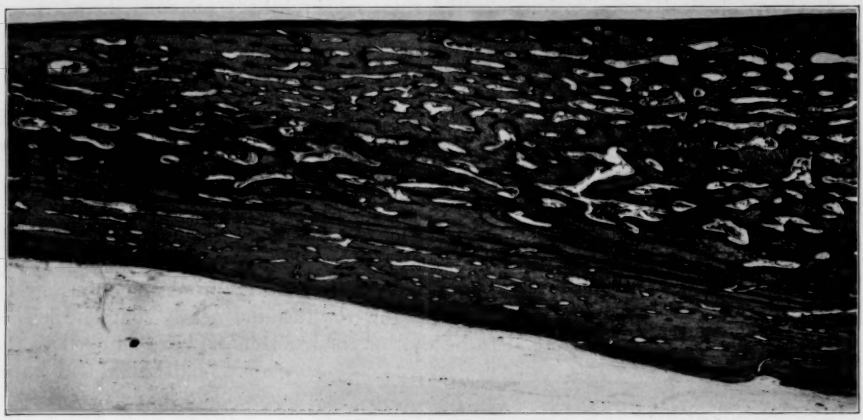


FIG. 10-A

FIG. 10-B

Figs. 10-A and 10-B: Two sections of the skull are shown to demonstrate absence of diploë. Fig. 10-A represents the more common histological structure; Fig. 10-B represents an area where the inner table (*A*) is discontinuous and the immature bone texture is seen.

was seen. There was complete degeneration of the ganglion cells of the retina. Some small hemorrhages were present in the sclera as well as in the retina.

DISCUSSION

Thorough clinical discussion of osteopetrosis may be found in McCune and Bradley's review of the literature and in van Creveld and Heybroek's more recent report. The metabolic and chemical study by Pincus, Gittleman, and Kramer constitutes the most complete recent report of this phase of the disease, for which the paper by Schachenmann provides additional data. The data of genetic interest have been summarized by Hanhart. The roentgenographic appearance and variations have been described by Pirie and Fairbank. Therefore, these phases of the problem will not be discussed in relation to the present case report.

Osteopetrosis, as understood in this paper, manifests the following characteristics:

1. It is generalized and affects all bones equally.

2. It is present at birth and is progressive. In some cases the condition has been recognized *in utero*.

3. It is often hereditary, with recessive autosomal genetic features.

4. Hematological complications are the rule; myelophthisic anaemia, hemorrhage, and infection usually are responsible for an early fatal outcome. Three cases have been reported as surviving into adult life, and in one of these the diagnosis is open to question.[20]

The patients are nearly always retarded in all phases of development and often show rachitic tendencies. The characteristic effects on the bones and the blood chemistry then complicate the clinical picture. Other complications which result from skeletal abnormality are optic atrophy, deafness, and occasionally osteomyelitis. The blood chemistry shows no characteristic changes, but analysis of the bones has yielded values indicating increased calcium and phosphorus content in all areas, and increased carbonate in the chondro-osseous complex (Pincus, Gittleman, and Kramer).

Roentgenographically, a homogeneous opacity of the bones is present in almost every case. There is complete obliteration of the marrow cavities and nearly complete loss of trabecular structure. The bones tend to be shorter than normal and are clubbed at the ends. Longitudinal and transverse bands of decreased density often are present in the metaphyses. Diagnosis is rarely based on clinical findings alone. It is usually the result of a roentgenographic examination for an unrelated condition or for explanation of the severe anaemia.

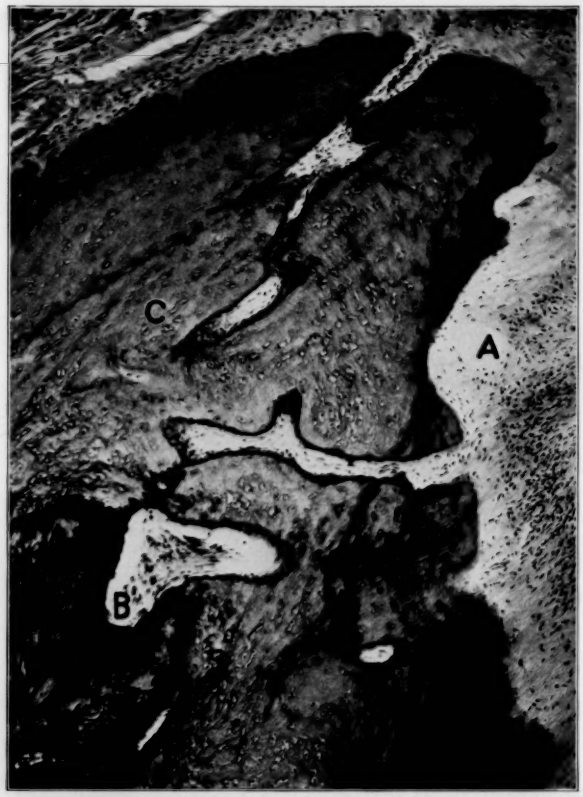


FIG. 11

Area of skull adjacent to a suture. Suture is seen at *A*. Immature, basophilic, fibrous, cellular bone seen at *B*. Outer table is at *C*.

The present report aims to discuss the pathology of the condition and its relation to the findings and treatment in this case. The pathological study of osteopetrosis is contained in relatively few reports, of which the essential ones are listed. Only three of these [13,17,20] include the study of long bones in their entirety, and, as Zawisch-Ossenitz has shown, the intimate macro-microscopic reconstruction of long bones adds to the understanding of this anomaly of bone.

The study of the viscera in this case, as in the previous reports, yielded no clue to the origin of the skeletal disturbance. Serial sections of the pituitary gland, study of all four parathyroids, and repre-

sentative sections of all the other organs were non-contributory. Study of the blood during life and of the bone marrow and extramedullary hematopoiesis at the postmortem examination also presented no new data concerning the typical myelophthisic anaemia.

It thus appears that an abnormality of bone is the basic one in osteopetrosis. Numerous observers have speculated upon the nature of this abnormality. The most prevalent concept, expressed in diverse ways, is that of faulty differentiation and development of the mesenchyme. Just what this faulty development means in terms of the sequences of bone formation has been variously interpreted: (1) as a partial or total inhibition of bone resorption (Dijkstra, Schmidt, van Creveld and Heybroek); (2) as disturbances of endochondral sequences (Nussey); (3) as disturbance in tissue equilibrium (Gerstel)—which presumably means abnormal predominance of deposition over resorption; (4) as damage to the bone-forming blastema during one phase of development, thus retarding the differentiation of bone tissue (Zawisch-Ossenitz); (5) as disease of the sclerogenous and myelogenous anlage leading to alteration in the bone and blood-forming tissues (Pines and Lederer).

While we do not presume to offer a more comprehensive explanation of the bone disturbance, we do believe that the pathological findings in this case, when added to the previous reports, merit review of certain essentials in the bone picture, which may lead to a further understanding of the essential disease entity. We will present the evidence in this and other reported cases which seems to offer any pertinent explanation.

1. All bones are affected, and they are affected in like manner and degree. While some authors have attempted to classify cases as marble bones in which some bones remained undisturbed, or less involved than others [2,13], it seems desirable to exclude those cases without generalized involvement. Nearly all the reports on atypical cases did not include tissue examinations.

2. The membranous bones show changes analogous to changes in bones formed from cartilage. This, together with the fact that all other connective tissues, including cartilage, exhibit no demonstrable lesion, focuses our attention on the process of bone formation.

3. Growth, while retarded, continues. The cartilage maturation sequences in our case and in published photomicrographs are not unusual and vascular penetration of the hypertrophic cartilage cells seems to occur normally. These are the essential microscopic features which always characterize the elongation of bone. The histological pictures of bone deposition and resorption, where such processes are occurring, contain all the normal cellular and matrix elements for such structural alterations. In osteopetrosis there is a disturbance of the normal sequences of resorption of the primary spongiosa, formation of secondary spongiosa, and ultimate disappearance of the cancellous bone as medullary cavity and cortex are formed. The abnormal feature in the chondro-osseous complex of osteopetrosis is the quantity of matrix (cartilage and bone) remaining which normally undergoes such rapid resorption. Thus, very little of the primary spongiosa is resorbed, while the deposition of bone and osteoid upon the cartilage matrix continues.

While many authors remark upon the rapidity of fracture healing, no previous histological study of this phase of the disease has been published. The rapid rate of healing of fractures is in marked contrast with the delay in remodeling sequences involving growth. The fact of rapid repair implies adequate local material and organization needed for normal bone resorption and deposition. When an adequate stimulus for repair is provided, the remodeling sequences in the repair of callus seemingly are also delayed. This point should be verified in future cases where fractures of the compacta occur, inasmuch as all the fractures in the present case were metaphyseal.

4. All of the normal architectural components of bone (cancellous and cortical bone, Haversian systems) can be found at one site or another within the marble bone, with the single exception of a tubular marrow cavity.

5. If we turn from consideration of bone as a complex of tissues and consider it as an organ, we note that the general architectural outlines in osteopetrosis are closely allied to those of analogous normal bones. The femur is obviously a human femur, the tibia, a tibia, *et cetera*. Thus we need not speculate upon the influences, nebulous as they seem, which determine the shape and size of bones. We may best describe the variation from normal of the general bone architecture as a delay in the remodeling sequences. Thus, normally a certain amount of cartilage matrix persists in the primary spongiosa of infants; in marble bones much more persists. The consequence is the club-shaped metaphysis containing the persisting calcified cartilage matrix trabeculae interlarded with osteoid and bone. In the diaphysis of infants normally some cancellous bone undergoing resorptive remodeling occurs endosteally on the cortical bone of the shaft, and this bone encloses a hematopoietic marrow cavity—in marble bone this cancellous element persists to a sufficient extent to preclude formation of the marrow cavity.

Normally, at the age of two years, a space forms between the inner and outer tables in the calvarium by resorption of the cancellous bone and replacement by hematopoietic marrow; in marble bones this cancellous bone persists inordinately and remodeling is delayed.

6. All of the cartilage matrix enclosed in the bone proper and nearly all of the bone matrix histologically seems well or even excessively calcified. Kramer and his associates reported increased calcium content of bone in this disease but did not differentiate the calcium content of the chondro-osseous matrix from that of the non-cartilaginous portion. However, despite this plenitude of calcium, there are fairly extensive areas of undoubted osteoid formation. Ordinarily, minimal osteoid formation is seen in normal infants' bones. This osteoid, conforming to no particular pattern of deposition but occurring mostly in the chondro-osseous complex, can be correlated with a lowered serum calcium; in the author's patient this was the case despite adequate milk intake and increased vitamin dosage. The susceptibility to rickets of patients with osteopetrosis is well known. Some disturbance of the calcium linkage therefore seems probable.

It is evident from the sections in this case and from published photomicrographs that all resorptive processes occur principally in relation to calcified matrices and not to osteoid or uncalcified cartilage. It may be pertinent to state that in rickets resorptive processes are also regularly preceded by calcification of matrix. Calcification may thus be one essential prerequisite of resorption.

7. Some evidence has been brought forward by Zawisch which indicates that marble bones retain representations of all stages of the development of the bones. This should include the initial vascular invasion of the cartilaginous anlage with concomitant formation of primary spongiosa, secondary spongiosa, cortex, and medullary cavity. Were this essentially ontogenetic explanation true, a vestige should remain of the original marrow cavity formed beneath the periosteal bony ring just prior to vascular invasion of the center of the cartilage anlage. This cavity, as measured in the femora and humeri of eight foetus, measured less than one centimeter in length. The retention of this cavity in osteopetrosis has never been demonstrated.

In the author's patient the distance between the proximal and distal cones of the chondro-osseous complexes in the long bones was several centimeters, representing resorption of several centimeters of the primary chondro-osseous matrix. These facts are stated to introduce the hypothesis, accepted by many observers, that osteopetrosis is a disease characterized by a disturbance in the bone-forming mechanism primarily at a certain phase of development and thereafter with exacerbation and remission. That there is exacerbation and remission of the hematological phase of the disease is unquestionable, but whether this may be due in great part to infection or to diet (availability of calcium and vitamins) is open to question. The hematological factors in osteopetrosis are not as unvarying as the skeletal characteristics, and the severity of the two often is not proportional. The reasons

for this are quite obscure. In the present case, however, the hematological and the skeletal defects were severe, progressive, and without remission. As regards the skeletal defects, many authors consider the transverse lines at the metaphyses to represent exacerbation and remission. We have included a series of photomicrographs to demonstrate that these lines represent fractures which originally occurred at the metaphysis. These fractures healed by means of cancellous bone as growth proceeded, and thus interrupted the continuity of the chondro-osseous matrix with cancellous bone and accompanying fibrovascular marrow. No signs of a change in the rate of the disease process could be found in our case and the growth rate, both in total body length and the length of individual bones, was proportional to the normal although, as stated, quite retarded. It is therefore probable that in this case the noxious influence involving bone formation was present from the beginning and was exerted without change throughout the patient's life.

The use of vitamin A in high dosage deserves explanation. Because of the increase in remodeling which occurs with high dosages in animals (Wolbach) it was thought that a similar principle might operate in this case. Despite good absorption and fairly long-continued administration, no effect was seen. A similar rationale in promoting resorption by use of parathormone was propounded by van Creveld and Heybroek, also without clinical benefit.

A search of the literature has disclosed references to osteopetrosis in the rabbit, chick, and mouse. In none of these are the bone changes identical with those found in man. The fibrous marrow, increase in trabeculation, and absence of marrow cavity seen in animals with osteopetrosis resemble the osteosclerosis seen occasionally in leukaemia, but the characteristic persisting chondro-osseous complex is not seen. The bones of the normal foetal manatee as reported by Fawcett correspond to those in human osteopetrosis, but no evidence was found in this case to support his suggestion of the possibility of endocrine etiology.

After reviewing the evidence presented, the following conclusions are suggested:

1. The bone lesions in osteopetrosis constitute the primary morphological abnormality of the disease. Hematopoietic deficiencies are the main source of disability, although these may bear no quantitative relation to the degree of bone involvement. Dietary and infectious influence may be of primary importance in the hematological picture.

2. The bone lesions in generalized osteopetrosis are best viewed as abnormalities in remodeling sequences leading to absence of marrow-cavity formation and retarded resorption of calcified cartilage matrix and spongiosa. These may be further due to abnormalities in the calcium salts or in the matrix which binds them.

3. The consequences of the delay in remodeling are the formation of conical chondro-osseous complexes and absence of a marrow cavity, which constitute the principal bone abnormalities.

4. The transverse lines in the metaphyses of osteopetrotic bones are fractures in various stages of healing. These presumably occur because of the increased fragility of the bones, particularly at the subepiphyseal region and in the areas where the cortex joins the chondro-osseous complex. The rapid rate of repair of these fractures contrasts with the delay in remodeling sequences.

5. Vitamin A in prolonged high dosage has had no observable effect on the course of one case of osteopetrosis.

NOTE: Grateful acknowledgment is made to Dr. S. Burt Wolbach, under whose direction this study was carried out.

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THERAPEUTIC ACCELERATION OF BONE AGE IN OSTEOGENESIS IMPERFECTA

A Case Report

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Extensive pathological studies have not revealed the cause of osteogenesis imperfecta.

The case of osteogenesis imperfecta tarda presented herewith features a number of unusual as well as the usual characteristics of the disorder. It portrays the "slender, fragile bone type" described by Fairbank, in which fractures do not occur until late infancy or early childhood. The roentgenographic appearances are characteristic; the shafts of long bones become very slender; their ends are expanded and honeycombed; the cortices of tubular bones are pencil thin; and moderate osteoporosis is generalized.

This case is of interest because it is an isolated instance in which bone age has been markedly advanced by treatment with sex hormones.

CASE REPORT

A Negro female was first admitted to the University Hospital on September 10, 1944, at the age of four months because of fretfulness of one week's duration. No history of trauma could be elicited. She had been delivered at home at full term. Until her admission to the Hospital, she had been breast-fed and had received no orange or other fruit juices or cod-liver oil. The mother, father, and five older siblings were living and well. No constitutional afflictions or congenital anomalies in the family were reported.

TABLE I

AGE OF PATIENT	SERUM ANALYSES								URINE
	Calcium mg./100 cc.	Phosphorus mg./100cc.	Alkaline P'tase*	Acid P'tase*	Tot. Prot. mg./100cc.	Alb./Glob. Ratio	NPN mg./100 cc.	Cholesterol mg./100 cc.	Sulkowitch's Test 24-Hour Specimen
2 Yrs. 3 Mos.	12.4	4.7	12.6						
5 Yrs. 9 Mos.	10.5	4.4							1+ to 2+(Normal)
6 Yrs. 5 Mos.	11.3	5.2	4.1	3.2	7.11	3.3/3.8	25.0	175	1+ to 2+

* King-Armstrong Units

The physical examination revealed no unusual conditions except abnormal motion and bowing of the shaft of the left femur. Roentgenograms showed an oblique fracture of the lower third of the left femur; the osseous architecture was not shown to be appreciably changed.

Bryant's overhead traction was applied, and the fracture healed rapidly. Considerable callus appeared within eleven days. Bottle feeding, orange juice, and cod-liver oil supplanted breast feeding. She remained in the Hospital three weeks.

She again entered the Hospital at the age of two years and three months because of a transverse, subperiosteal fracture of the lower third of the left femoral shaft which resulted from a fall from a bed two feet high.

Since her last visit to the Hospital, the patient had been continued on bottle feeding, supplemented by cod-liver oil and orange juice. She had been able to crawl on all fours, but she could not stand unaided.

On physical examination, a bowing deformity at the fracture site was seen again. The patient was well developed and well nourished, and her stature was normal for her age. The lower limbs were very slender, and the muscles were weak and wasted. Dentition was normal, but the teeth were brownish gray rather than white; they were not carious. Expecially striking were the deep china-blue sclera. The cranial sutures and the fontanelles were closed, and the shape of the head was not unusual. There were no other abnormalities.

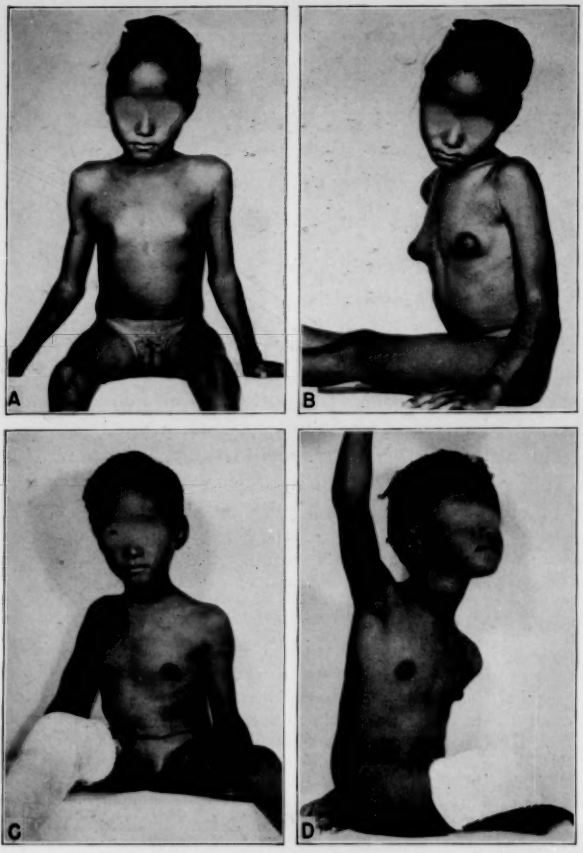

FIG. 1

Photographs show regression of secondary sexual characteristics. *A* and *B* were taken after ten months of estrogen-androgen therapy; *C* and *D* were taken ten months later. No endocrines were administered after *A* and *B* were taken.

Roentgenographic studies of the pelvis and of the upper and lower extremities revealed the fresh fracture. Thinning of the cortices, osteoporosis, and prominent intramedullary striations, limited largely to the long bones of the lower limbs, were apparent.

Following the second fracture, dietary therapeutic measures were instituted. The diet provided was enriched by vitamins, calcium, and phosphorus.

During the next four years, she sustained five additional fractures of the long bones of the lower extremities, all from trivial or unrecognized injuries. The fractures healed readily with abundant callus formation.

The first three fractures were of the left femur; the fourth, of the right tibia and fibula; the fifth, a supracondylar fracture of the right femur; and the sixth and seventh were of the right tibia and fibula. It was interesting to note that the medullary canals had been reestablished before each additional fracture occurred. With the exceptions of the first fracture of the left femur and the supracondylar fracture of the right femur, all fractures were subperiosteal.

A summary of pertinent laboratory findings is presented in Table 1. Peripheral blood counts and routine urinalyses were within normal limits; the Kahn test was negative on three separate admissions to the Hospital.

Hormonal therapy was started following the fourth fracture, at the age of four years and nine months, and was continued without interruption for ten months. The medication consisted of 0.1 milligram of stilbestrol daily and 10 milligrams of methyl testosterone on alternate days. This combination produced a puberal development of the breasts with large, deeply pigmented areolae and erectile nipples, prominence of the mons veneris, and coarse pubic and axillary hair. She did not menstruate. During this ten-month period of hormone administration, no fractures were sustained.

Following the estrogen-androgen therapy, no changes were shown by roentgenograms except a striking and widespread acceleration of ossification centers.

About three weeks after the medication had been discontinued she had a fifth fracture.

Subsequent to dietary and hormonal therapy, aluminum acetate was administered. Ghormley's modification of Helfet's mixture [13] was employed, which has been well tolerated by the patient for nine months. It was during the eighth month of aluminum acetate therapy that the right tibia and fibula were again fractured. This seventh fracture occurred without any known trauma at the age of six years and four months.

To exclude the possibility of supervening rickets, the child was readmitted to the Hospital for further study five weeks after the seventh fracture. Laboratory studies threw no new light on the case and roentgenograms showed no evidence of rickets. The typical roentgenographic appearances were unaltered.

Physical examination at this time revealed no stunting of height (46.5 inches), normal proportions of span to height (1:1) and of upper skeletal to lower skeletal segments (1.25:1). Except for very delicate features, growth and development were apparently normal. The fingers were long, slender, and graceful. The fourth and fifth digits were symmetrically shortened in both hands. Dentition was still normally advanced. However,

even the permanent three lower incisors were poor in enamel content. The lower limbs were spindle-shaped at the knees and ankles. There was a saber-shaped anterior bowing deformity of the right leg. In comparison with the condition ten months earlier, there was a noticeable regression of the secondary sexual characteristics (Fig. 1).

FIG. 2-A

FIG. 2-B

FIG. 2-C

FIG. 2-D

Fig. 2-A: The carpus and hand are normal for the age of two years and three months.

Fig. 2-B: Carpus and hand at the age of five years and nine months. Twelve months after hormonal therapy started, the bone age is advanced by at least five years; note the presence of the pisiform which normally appears at ten to thirteen years of age.

Fig. 2-C: No difference in carpus and hand is shown in roentgenogram taken six months later than Fig. 2-B.

Fig. 2-D: The carpus and the hand of a normal subject, aged eleven years, for comparison. Note the absence of the pisiform.

SIGNIFICANCE OF LABORATORY FINDINGS

Estimations of serum calcium, inorganic phosphorus, and alkaline phosphatase are normal in osteogenesis imperfecta. If there is a superimposed disturbance, such as avitaminosis D [21], the levels will be altered accordingly. High levels of alkaline phosphatase which have been reported in osteogenesis imperfecta are not related to the primary disorder but are incidental to fracture repair. Hansen has demonstrated an almost complete absence of alkaline phosphatase in the periosteum and in the subperiosteal tissue, where normally it is abundant. In the region of the callus, however, phosphatase activity was greatly increased [12]. The histopathological features of this disease have been ably described by Key and a repetition here is unnecessary. Suffice it to say, that the fundamental failure is that of the osteoblasts which are few and practically non-functioning.

FIG. 3

Lateral roentgenogram of lower thoracic vertebrae when patient was six years old. No changes diagnostic of osteogenesis imperfecta are shown. Note the early appearance of apophyses for the upper and lower rims of the vertebral bodies and the persistence of anterior clefts.

Small doses of sex hormones are known to have no effect on the serum values of calcium, phosphorus, and alkaline phosphatase [17]. Positive calcium balance has been obtained after large doses of testosterone, and serum values have in some instances gone upward. In acromegaly, estrogens will depress high serum-phosphorus values.

From laboratory evidence in this case, it was seen that rickets had not supervened during the period of aluminum-acetate therapy.

CLINICAL FEATURES

Stunting of growth, frequent fractures of long bones, and blue sclera are the prominent features of this disease. Diminished stature is a result of fracture deformities of the long bones and is not related to the primary defect of ossification.

The teeth are often translucent and carious, apparently due to defective enamel formation. It seems strange, however, that a generalized mesenchymal defect should be reflected in an epithelial organ. Otosclerosis is a late accompaniment in patients with blue sclera. Although the blood vessels are supposed to be brittle, ecchymoses are rarely noted in fractures associated with osteogenesis imperfecta [14].

The lower limbs are usually more severely affected than the upper limbs. Hence, fractures are often limited to the long bones of the lower extremities. The possibility of osteogenesis imperfecta should not be overlooked when fractures are limited to one limb [21].

Blue Sclera

In many respects this is the most interesting aspect of the disease. Blue sclera are reputed to occur in 100 per cent. of the hereditary cases, but this may be the only manifestation of the condition. It is not surprising, however, to encounter isolated examples without hereditary traits, as this is characteristic of other dystrophies.

The intensity of the blueness is no index of the severity of the disorder, as demonstrated in this instance in which the sclera are intensely blue while the osseous fragility

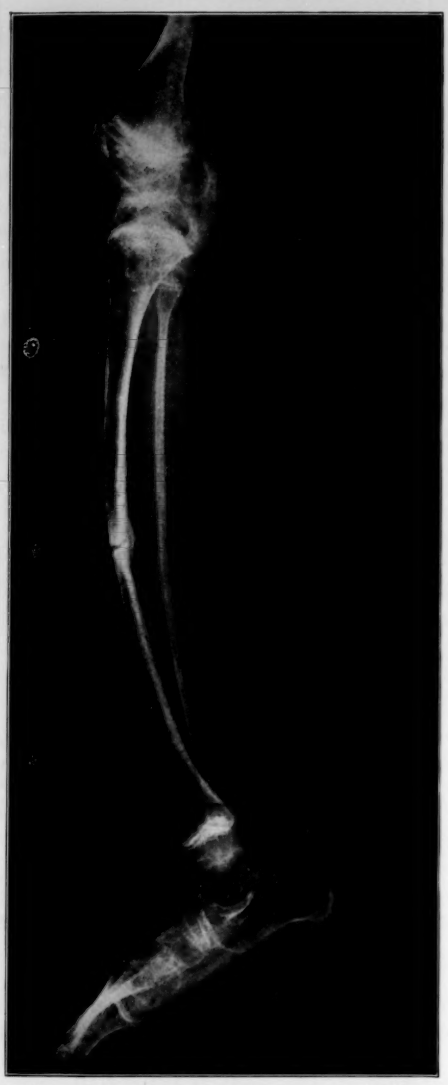

FIG. 4-A

FIG. 4-B

Typical roentgenograms. The patient at this time was six years and five months of age. Marked osteoporosis is shown. The shafts of the long bones are slender; the ends of these bones apparently are expanded.

Fig. 4-A: Note subperiosteal fractures of tibia and fibula; the gradual anterior bowing in the supracondylar portion of the right femur, a residual deformity from the old fracture; lamellation of cortex of shaft of tibia.

Fig. 4-B: Epiphyseal lines are normal; irregular, sparse, widely separated trabeculae and honeycombing are shown; the thin shell of the cortex, epiphyses, and metaphyses together with irregular subchondral "cystlike" areas, especially in the epiphyses, should be noted.

is relatively mild.

Kaplan attempted to relate the variations in color to the caliber of the blood vessels of the conjunctiva and choroid by instilling eserine and then atropine. No difference was detected. He also made the keen observation that, in his cases, the intensity of the blue sclera changed at various examinations. (In our case, it was the patient's father who brought this unusual phenomenon to light; the sclera have varied from a deep blue to a murky, grayish blue on different occasions.)

Knaggs disapproved of the teaching that the blue color was due to the greater visibility of the pigmented choroid through a thin sclera. From such investigations as had been made, he concluded that there was no difference between the measurements of the thickness of the sclera of normal subjects and the sclera in cases of osteogenesis imperfecta.

The concept that the translucency of the sclera is due to some alteration in the fibrous tissue is probably nearer to the truth. In support of this contention is the unusual suscepti-

bility to sprains characteristic of individuals with blue sclera who do not have brittle bones.

ROENTGENOGRAPHIC APPEARANCES

In osteogenesis imperfecta, the fractures are usually incomplete or subperiosteal with little displacement and no comminution. Callus forms readily and is often more abundant than that in normal patients. Markedly irregular, hyperplastic callus formation with or without evidence of fracture, has been observed to simulate sarcoma.[7] Deformities do not result from the plasticity of osteoporotic bone. They are due to the healing of fractures in malposition or to the gradual bending of the bone from repeated, numerous, incomplete fractures of the fragile cortex[16].

TABLE II

AGE OF PATIENT	OSSIFICATION CENTERS PRESENT	NORMAL	LATE	EARLY	CENTERS NOT PRESENT
BONE AGE PRIOR TO HORMONAL THERAPY (Note: Bone Age Same as Chronological Age)					
4 Mos.	Talus, Calcaneus, Cuboid, Upper Tibia, Lower Femur Femoral Head, 11 Mos.	X		X	Lower Tibia, 5 Mos.
2 Yrs., 3 Mos.	Lower Radius, Capitate, Hamate, Phalanges of Hand, Metacarpal Heads, 2 - 3 - 4				Base 1st Metacarpal, 3 Yrs. Lower Fibula, 2 Yrs.
	Capitellum, Lower Tibia	X			Patella, 3 Yrs.
3 Yrs., 5 Mos.	Lower Fibula		X		Greater Trochanter, 4 Yrs.
	Patella	X			U. Pubis and Ischium, 8 Yrs.
4 Yrs., 9 Mos.	3 Cuneiforms, Tarsal Navicular	X			Upper Fibula, 4 Yrs. Calcaneus (Apophysis), 10 Yrs.
BONE AGE AFTER HORMONAL THERAPY (Note: Marked Acceleration)					
4 Yrs., 11 Mos.	Upper Fibula (Small nucleus just visible)		X		
5 Yrs.	Upper Fibula (Full Size)		X		
5 Yrs., 9 Mos.	Metacarpals, Phalanges of Hand, Lower Radius, Capitate, Hamate, Triquetrum, Greater and Lesser Multangulars, Lunate, Carpal Navicular	X			
	Lower Ulna with Beginning Styloid			7 Yrs.	
	Pisiform			10-13 Yrs.	
	Calcaneus (Apophysis)			10 Yrs.	
	Lesser Trochanter of Femur			10-14 Yrs.	
	U. Pubis and Ischium			8 Yrs.	
6 Yrs.	Upper and Lower Rims of Vertebral Bodies			8-18 Yrs.	
	Iliac Crests			16 Yrs.	
6 Yrs., 5 Mos.	Hand and Carpus: No change from 5 Yrs., 9 Mos.				Lateral Epicondyle of Humerus, 13 Yrs.
	Medial Epicondyle of Humerus, Upper Radius, U. of Humeral Head to Greater Tuberosity	X			Acromion, 15 Yrs.
	Olecranon			10 Yrs.	
	Trochlea			11 Yrs.	
	Sternal End Right Clavicle			18 Yrs.	

U - Union
Numbers indicate normal age of appearance of center.

The fairly regular epiphyseal lines seen in the roentgenograms exclude scurvy, rickets, and congenital syphilis. Although periosteal growth of the long bones is inhibited, epiphyseal growth is normal. The diaphyses become increasingly slender with age, more pronounced in the long bones of the lower extremities. The contrast between the normal epiphyses and the fragile shafts makes the ends of the bones appear expanded [21].

Moderate osteoporosis is generalized. The severely involved long bones show honeycombing at their ends. Trabeculae are sparse, delicate, widely separated, and often irregularly whorled. Metaphyseal cortices are especially thin and sometimes are lamellated. Occasionally the cortices of the shafts of slenderized tubular bones are relatively thick with very narrow medullary canals.

Short metacarpals are sometimes associated with osteogenesis imperfecta. The fourth metacarpal is the one which is most consistently shortened. According to Brailsford, this is an expression of an hereditary tendency for premature fusion of certain epiphyses. (The short fourth and fifth metacarpals in this case are not related to early epiphyseal closure; in fact, the epiphysis of the fifth metacarpal head was slower to appear than the epiphyses of the other metacarpals (Figs. 2-A, 2-B, and 2-C).)

THERAPY

Evidence for incriminating the endocrines in osteogenesis imperfecta is not conclusive [16, 26]. Many preparations have been used without real benefit. Bickel, Ghormley, and Camp revived the use of Hansen's thymic extract to little avail.

Impaired phosphorus metabolism has been implicated by a number of authors. Fleming and his associates advocated adding dilute hydrochloric acid to milk because their patient had no free hydrochloric acid in the stomach, inferring from this a basis for poor phosphorus absorption. Ghormley and Hinchey used aluminum acetate in one case of osteogenesis imperfecta in which, according to them, clinical improvement warranted further trial with this medication. Helfet's hypothesis for the use of aluminum acetate was to reduce the absorption of phosphorus, thereby reducing the stimulus for overproduction of parathormone.

In our case, methyl testosterone and stilbestrol were employed to hasten puberty, so that there might occur spontaneous arrest of the fragility and the liability to fractures. These substances were administered in small doses for a long time to avoid the undesirable effects of menstruation and early fusion of the epiphyses. It is probably coincidental that no fractures were sustained during the period of hormonal therapy.

The futility of all the measures attempted in this case is reflected in the roentgenograms which showed no changes of note. Fractures have occurred unabated.

BONE AGE AND SKELETAL MATURATION

The sensitive indicators of endocrine dysfunction in the growing child are: the time of the appearance of ossification centers and the time of skeletal maturation. The pituitary and thyroid glands and the gonads are intimately involved in determining the level of osseous development and the time for the closure of the epiphyses. Retardation of bone age is associated with certain hypofunctioning endocrinopathies, while hyperfunction usually results in the acceleration of bone age. Clinical use of replacement therapy for endocrine hypofunction has produced advance of delayed bone age to normal or slightly beyond normal. This is particularly true in cretinism. In some endocrine disorders, substitution therapy has served only to hasten closure of the epiphyses.

In our case of osteogenesis imperfecta, a decided advance in bone age in all of the ossification centers resulted from the estrogen-androgen medication, but there was no stimulation of premature epiphyseal closure. Estrogens and androgens have been shown to intensify skeletal aging in normal experimental animals [17, 22]. However, so far as we have been able to determine, this is the only clinical case with no endocrine dysfunction in which bone age has been markedly accelerated by sex-hormone therapy.

Snapper has pointed out that the tendency to early epiphyseal union observed in his case of osteogenesis imperfecta has been described in other instances of this disease.

In Kaplan's case of a white female six years old, there was reported a definite acceleration in the appearance of the centers of ossification. There was no knowledge of the course of skeletal aging prior to six years of age and the follow-up did not exceed several months. Brailsford has indicated that advanced bone age is a feature in some cases of osteogenesis imperfecta in early life. He states that the capital femoral epiphysis appears at an age as early as three months and that the epiphyses for the superior and inferior rims of the vertebral bodies appear as early as the fourth year.

It is not possible to form an idea of skeletal development from such single indicators as the carpus and the hand. There is considerable variation of bone age in the various ossification centers. Not until the advanced bone age was accidentally discovered in this case was any attempt made at exhaustive studies of the osseous development. The number of ossification centers available for study in all the roentgenograms which have been taken were deemed sufficient to prove that prior to the treatment with sex hormones skeletal age

had advanced at a normal rate. Following the therapy there was a striking widespread increase in bone age. All available roentgenograms were reviewed, and the data are assembled in Table II.

COMMENT

Although there has been a definite regression of the secondary sexual characteristics in the ten months following the cessation of the treatment with methyl testosterone and stilbestrol (Fig. 1), no change has been observed in the carpus and the hand (Figs. 2-A, 2-B, and 2-C). Since the apparent stimulus has been removed and the epiphyses have not prematurely united, it is assumed that the skeletal age will be arrested until the chronological age approaches it. This may prove to be mere speculation; nevertheless, there is little reason to believe that this interlude of endocrine therapy will have significantly altered the patient's ultimate stature.

Aluminum-acetate therapy will be continued, if well tolerated and if no evidence of rickets develops. Guarded activity, careful handling, and cautious weight-bearing will be enforced until maturity is reached. It is hoped that at that time there will be a spontaneous arrest of the fragility of bone since it has been noted that the tendency to fracture diminishes after puberty.

Although some cases of osteogenesis imperfecta in earlier years show advanced bone age, this case did not. It is a striking clinical example, corroborating animal experimentation, in which the sex hormones have been shown to markedly accelerate osseous development in a patient with no endocrine dysfunction.

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THE INFLUENCE OF PRESSURE AND TENSION ON GROWING BONE IN EXPERIMENTS WITH ANIMALS

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The purpose of the experiments to be presented in this paper was to solve certain problems connected with the influence of mechanical factors on the growth of bones. German scientists conducted experiments on animals by methods similar to those of Haas [5, 6, 7] before they knew of his work. While our findings have been extensively published in the German literature, a short summary for the benefit of American scientists may be justified.

For the last hundred years the influence of compression and tension on growing bones has been discussed in connection with the classical theory of bone deformities. In 1862 Hueter and Volkmann advanced the theory that compression inhibits the growth of bones and produces atrophy, while tension increases bone growth and the formation of osseous tissue. This theory was disputed by Wolff, who subsequently formulated his rule of the transformation of bones. Wolff claimed that both compression and tension lead to the formation of osseous tissue and to an increase in bone growth. In spite of much clinical and experimental work, no agreement on this problem has been reached. The reason for this lies in the fact that no distinction has been made by the various authors between growing and mature bone. Furthermore, sometimes the formation of bone tissue and bone growth have been considered identical processes. (It will be shown later that formation of bone tissue without longitudinal growth—that is, when longitudinal growth is inhibited—may, in fact, be possible.) In general, the methods used by these authors were too disparate to allow comparison of the results.

The writer has performed a series of experiments on the effect of pressure on bone growth. These experiments were arranged in such a way that tension and gliding were eliminated, and only one direction of mechanical force—in this case pressure—could possibly affect the bone. Thus the reaction of tissue to this force alone could be studied.

The animals used were growing dogs. A stainless-steel wire was passed in a sagittal direction through the knee joint between the cruciate ligaments. A hole was drilled through the diaphysis of the femur, also in a sagittal direction, and the wire was passed through the hole in an anteroposterior direction. The two ends of the wire were then twisted together. In some cases this wire loop was tied loosely (Fig. 1-A), while in other cases it was tied firmly so that the bone was under strong pressure immediately. A second drill hole was made proximal to the first and another piece of wire was passed through the bone in a sagittal direction; this wire was allowed to remain as a marker in order to determine whether the wire loop would move distally. This would be shown by an increase in the distance between the two wires. It was found that the distance remained the same in all cases, proving that there is no interstitial bone growth, and that longitudinal bone growth is caused only by the epiphyseal cartilage. In the course of time the primary pressure of the wire loop must therefore be constantly increased by the epiphyseal growth.

Figures 1-A to 1-D show such an experiment. The wire loop is not held firmly tight at the distal end of the femur. Roentgenograms made after four weeks showed that the wire loop was pressed deeper into the intercondylar notch of the femur by the force of growth. The wire loop was pressed well against the cortical layer, so that the oval shape of the loop was distinctly lengthened. The roentgenogram did not show any change in the epiphyseal area within the wire loop as compared with the contralateral side. After about three

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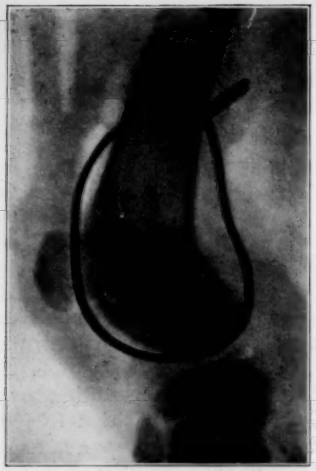

FIG. 1-A

Fig. 1-A: Experiment A. Showing position of wire loop immediately after operation. Note the distance from the marker to the loop and from the cortical layer to the loop.

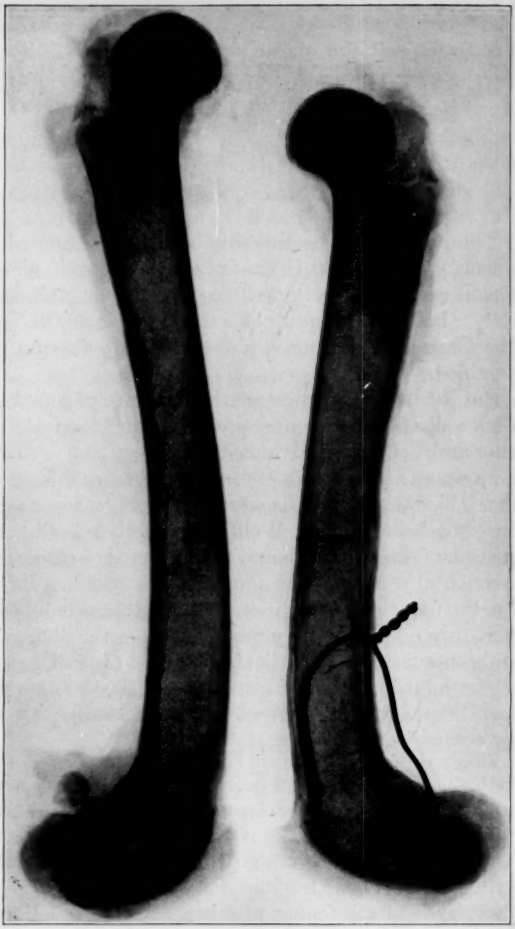

FIG. 1-B

Fig. 1-B: Anatomical specimen nineteen weeks after the experiment was begun. Note the shortening of the femur subjected to pressure, the change in the shape of the wire loop, and its close contact with the bone. No increase in the girth of the bone. The distance between the marker and the loop has remained the same.

months' time the growth, however, had increased the pressure of the wire loop to such an extent that further expansion was not possible. At this stage the roentgenogram for the first time showed quite distinctly that the epiphyseal line was narrower than that on the normal side.

The fact that the power of bone growth could deform the wire loop to such an extent and for three months produce no visible roentgenographic change in the epiphyseal line makes it obvious that the epiphyseal cartilaginous plate can bear, without any damage, a much higher degree of pressure than is effected under normal physiological conditions. Experiments revealed that a force of one kilogram was necessary to deform such a wire to that extent. This is a considerable force in view of the fact that the average weight of a young dog is only about two kilograms. The epiphyseal cartilage of one femur has to bear approximately 0.5 kilogram; this calculation is made without taking into consideration the tonicity of the muscles. Thus present theories regarding certain deformities or disturbances in growth may be based on an oversimplified conception of the mechanical factors involved.

Only an extreme increase in pressure leads to an inhibition of longitudinal growth and to a narrowing of the epiphyseal plate.

Figure 1-B shows both femora of the same dog after nineteen weeks. Measurements

revealed that the femur subjected to pressure was shorter by 1.5 centimeters. The area within the wire loop does not show an increase in girth. This must be emphasized, as many authors claim that, under pressure, bone compensates for a decrease in length by an increase in width [13–17]. This would mean that the total volume of bone remains unchanged, a fact which has been disproved.

With respect to the histological changes in the epiphyseal plate, some authors claim that the epiphyseal plate is narrowed under pressure [17], while others found that it is widened [13–16].

FIG. 1-C

FIG. 1-D

Fig. 1-C: Showing the distal epiphyseal plate in the normal femur.
Fig. 1-D: Showing narrowing of the epiphyseal plate in the femur subjected to pressure. Same magnification as in Fig. 1-C.

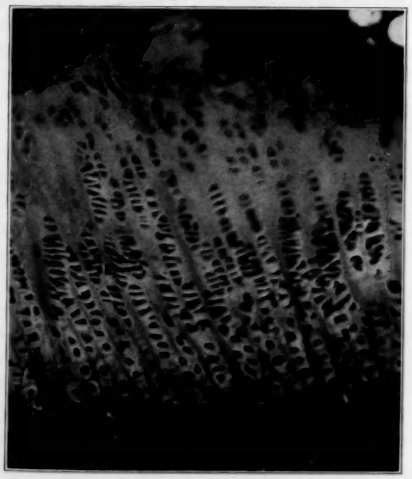

FIG. 2-A

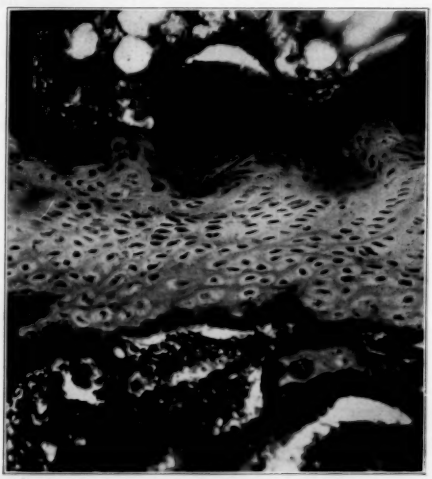

FIG. 2-B

Experiment B.

Fig. 2-A: Showing the epiphyseal plate of the normal femur in another dog.
Fig. 2-B: Showing narrowing of the epiphyseal plate under pressure on the contralateral side. Same magnification as in Fig. 2-A.

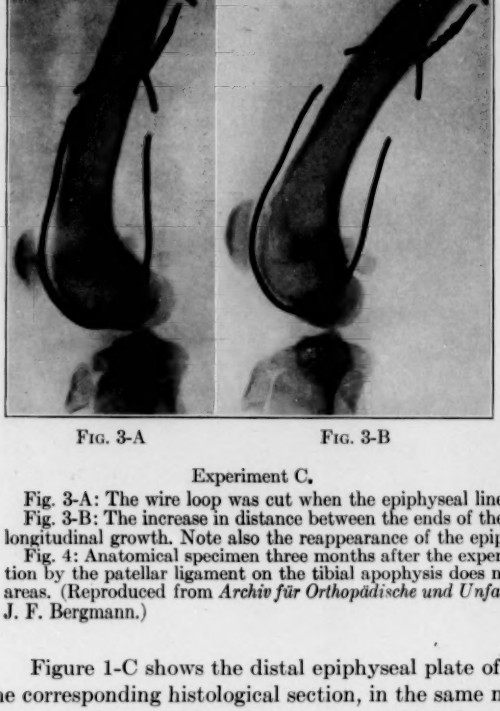

FIG. 3-A FIG. 3-B

Experiment C.

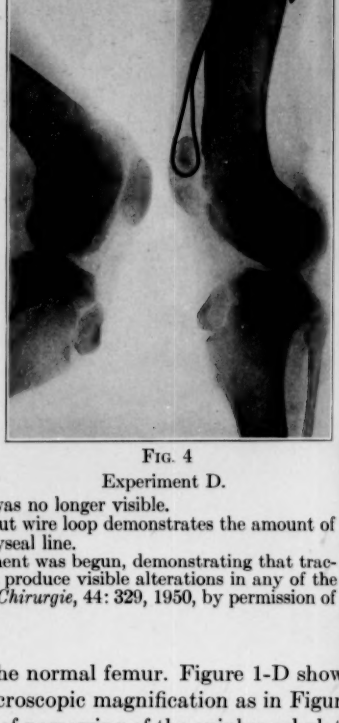

FIG. 4

Experiment D.

Fig. 3-A: The wire loop was cut when the epiphyseal line was no longer visible.

Fig. 3-B: The increase in distance between the ends of the cut wire loop demonstrates the amount of longitudinal growth. Note also the reappearance of the epiphyseal line.

Fig. 4: Anatomical specimen three months after the experiment was begun, demonstrating that traction by the patellar ligament on the tibial apophysis does not produce visible alterations in any of the areas. (Reproduced from *Archiv für Orthopädische und Unfall-Chirurgie*, 44: 329, 1950, by permission of J. F. Bergmann.)

Figure 1-C shows the distal epiphyseal plate of the normal femur. Figure 1-D shows the corresponding histological section, in the same microscopic magnification as in Figure 1-C, of the femur subjected to pressure. A high degree of narrowing of the epiphyseal plate is to be seen. The columns of cartilage cells have disappeared entirely. The epiphyseal plate takes an irregular course. In several places the cartilaginous zone is interrupted by the interposition of spongy bone. The fact that narrowing affects all layers of the epiphyseal plate is, however, more apparent in areas which are more highly differentiated and which lie closer to the metaphysis.

In Figure 2-B there is a similar but lesser change resulting from a different experiment. In this case the wire was tightened with a wire suture fastener to obtain a high degree of pressure immediately. As a result the experiment was completed within two months. Again an irregular formation of cells is to be seen. The epiphyseal plate is considerably narrowed, as compared with the epiphyseal plate on the normal side seen in Figure 2-A, which shows the corresponding histological section at the same magnifi-

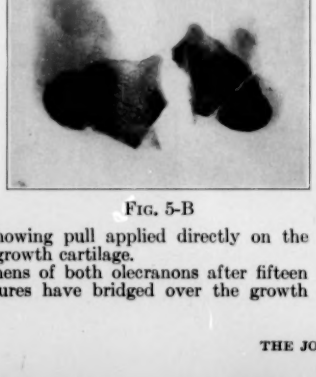

FIG. 5-A FIG. 5-B

Fig. 5-A: Experiment E. Showing pull applied directly on the apophysis, and changes in the growth cartilage.

Fig. 5-B: Anatomical specimens of both olecranons after fifteen weeks. Note that bone structures have bridged over the growth cartilage.

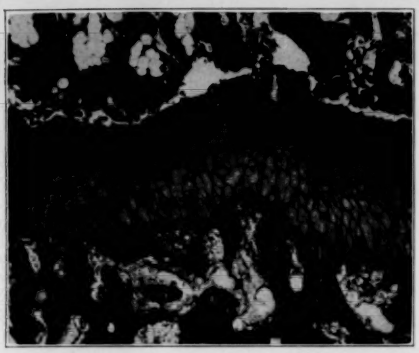

FIG. 5-C

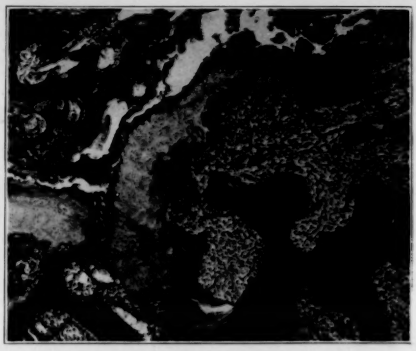

FIG. 5-D

Fig. 5-C: Showing the cartilaginous zone in the normal olecranon.
Fig. 5-D: Showing narrowing and irregularity of the cartilaginous zone on the side on which pull has been applied. Same magnification as in Fig. 5-C.

cation. It is evident that the extreme pressure inhibits the proliferation of the cartilage cells and consequently inhibits longitudinal growth. The formation of bone tissue proceeds at the expense of the cartilaginous tissue present in the area of growing bone, and hence no atrophy takes place.

It should be of some interest to recall the histological changes in the epiphyseal plate resulting from experiments with extirpation of the thyroid and pituitary gland [24–26], application of roentgen therapy on the epiphyseal plate [12,18], and high-fat or high-protein diet in growing mice [19,20]. Here similar histological changes—such as narrowing and irregularity of the epiphyseal plate, bony tissue extending into the epiphyseal cartilage, stunted growth, *et cetera*—may be seen as in the experiments described in the foregoing.

It has been said that the pressure must be extremely high in order to effect the changes described. It should be pointed out that the pressure must also be continuous. This was demonstrated in another experiment, in which the wire was cut anteriorly and posteriorly (Fig. 3-A) as soon as the epiphyseal line was no longer visible on the roentgenogram. In this instance the histological findings could be expected to correspond to those shown in Figures 1-C and 2-B. Figure 3-B shows the femur of the same dog as that in Figure 3-A seven weeks later. The wire ends have moved apart distinctly and the epiphyseal line has become visible again on the roentgenogram. It was evident that the femur had resumed its longitudinal growth after removal of the pressure caused by the wire. Eight weeks after the wire was cut the animal was sacrificed. Histological studies showed a hardly noticeable narrowing of the epiphyseal plate, and the grouping of the cells was almost normal. It may be concluded with some justification that, to a certain extent, changes in the areas of growth which are caused by strong mechanical forces may be reversed if these forces are removed while the subject is still in a stage of growth.

The fact that the changes described here were not caused by reactions to the operation or to the foreign material of the wire was established by control experiments. In these, dogs were subjected to the same operation, but the wire was not tightened, so that no pressure was applied. In these experiments there were no changes in the epiphyseal plate [3].

The experimental application of traction or tension to growing bone is, of course, more difficult than the application of pressure. It is evident that traction can be applied only at the apophyses. At first an attempt was made to increase the tension of the tendons attached at the apophyses. This method avoids the possibility of damage caused by the wire in the area of growth. The technique used in this experiment can be seen in Figure 4. A wire loop was passed through the patella and both ends were drawn through a hole drilled in the flexor side of the femur. There they were fastened over a piece of metal after

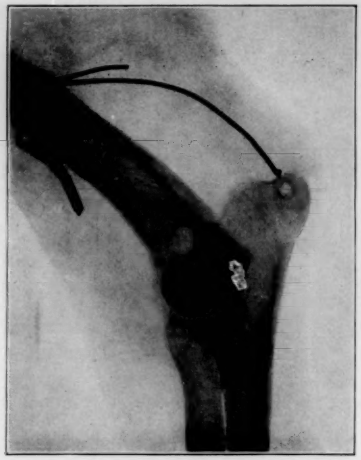

FIG. 6-A

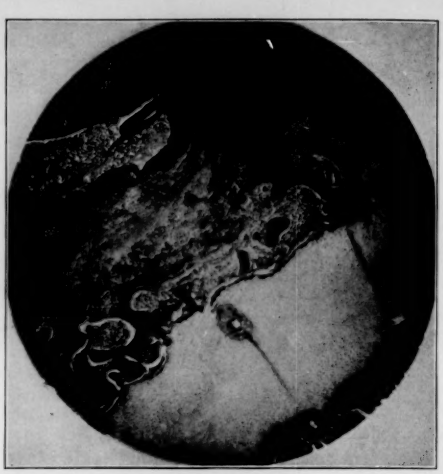

FIG. 6-B

Fig. 6-A: Experiment F. Spontaneous break of wire due to action of strong mechanical forces.
Fig. 6-B: There are no changes in the area of growth, as tension has ceased.

the wire loop was tightened as much as was possible and on full extension of the knee joint. Thus a permanent and maximum degree of tension was effected on the apophysis of the tibia by the patellar ligament. The flexor muscles tend to bring back the knee joint to a slight degree of flexion, as is typical in a dog. In this experimental arrangement the contraction of the flexor muscles must cause a pull at the tibial apophysis. Finally, the growth in length moves the wire loop, and with it the patella, in a proximal direction and thus increases the tension.

Figure 4 shows both knee joints three months after operation. It is important to state that neither the roentgenograms nor the histological sections show any changes in the spongy parts of the apophysis, or in its growth cartilage, or in the area where bone and tendon fibers meet. All the experiments conducted in this manner showed the same negative results.*

The collagenous fibers connecting the tibial apophysis with the tibial tuberosity as described by Lacroix [10] might explain the negative results in these experiments. These fibers are regarded by Lacroix as belonging to the patellar ligament. It is possible that the collagenous fibers serve as a balance against the tension of the patellar ligament.

Other experiments were arranged in such a way that the wire was directly affixed to the apophysis. A wire was passed through the olecranon in an anterior direction without damaging the growth cartilage. The elbow joint was fully extended and both ends of the wire were brought to the flexor side of the humerus and attached in the same way as in the femur. The effect of this experimental arrangement is the same as in attaching the wire to the tibial apophysis, except that the action of the tension is excluded, as the wire is passed directly through the bone.

Figure 5-A shows both the arrangement of the experiment and the change in the epiphyseal cartilage after five weeks. The epiphyseal line is somewhat indistinct on the roentgenogram, while small cysts in the metaphysis are to be seen. Figure 5-B shows the anatomical specimen of both tips of the elbow fifteen weeks after the experiment was begun. On the roentgenogram the epiphyseal line shows a bony structure.

In the histological section the epiphyseal plate appears irregular and narrowed, and the arrangement of its cells is disturbed (Fig. 5-B). This may be compared with the

* From a clinical standpoint, the view that Schlatter-Osgood disease is caused by an increase in the tension on the tibal apophysis is therefore open to doubt [3].

normal epiphyseal plate of the olecranon in the contralateral limb shown in Figure 5-C. It is important to note that the tension did not increase the longitudinal growth of the apophysis and did not cause any noticeable deformities.

To a considerable extent, the effects of tension on the area of growth and on the formation of bone tissue are similar to those of pressure. In both cases the proliferation of cartilage cells appears to cease. The formation of bone tissue proceeds at the expense of the available cartilaginous tissue. Thus growth comes to an end.

In the experiments in which tension was effected, it also appeared that the changes in each case were not caused by the trauma of operation, nor were they due to the foreign material of the wire. In some experiments the wire loop broke after several days, a sign of the strong mechanical strain (Fig. 6-A). No changes in the roentgenograms or in the histological sections were found in those experiments in which the wire had broken and the force of tension had consequently ceased to act. The histological section of an experiment in which the wire broke is shown in Figure 6-B. The epiphyseal plate is quite normal.

SUMMARY

No agreement has yet been reached on the opposing theories of Hueter and Volkmann on the one hand and Julius Wolff on the other. The writer's experiments with young dogs were made in order to contribute to the clarification of these controversial theories. The findings permit the following conclusions:

1. A permanent and maximum degree of pressure inhibits longitudinal bone growth and does not lead to a compensatory increase in girth. This inhibition of growth is due to the prevention of proliferation in the growth cartilage, which narrows and becomes irregular in its arrangement. New-bone formation, that is, the replacement of the available cartilaginous tissue, proceeds without any interruption. Atrophy of the bones does not occur.

2. Strong and permanent tension does not increase enchondral bone growth; on the contrary, it has nearly the same effect as compression when it is applied directly to the bone. The nature of the insertion of the ligament at the apophysis seems to be such that there is no danger of extreme unphysiological tension.

3. Changes caused by mechanical forces appear to be reversible to a certain extent, if these forces are removed before skeletal maturation.

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Therapeutic Acceleration of Bone Age in Osteogenesis Imperfecta

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(*Continued from page 948*)

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STUDY OF DISPLACED CAPITAL FEMORAL EPIPHYSES *

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A study has been made of a group of twenty patients with slipping of the capital femoral epiphysis treated conservatively, contrasted with a group of thirty-seven patients in whom internal fixation was employed. In this group of fifty-seven patients, sixty-four hips were involved.

Review of both series shows that changes in the metaphysis and epiphysis antedate the stated onset of symptoms. Some change in the relationship between the two also usually antedates the onset of symptoms. Generally the beginning of symptoms merely denotes the actual occurrence of considerable further slipping. This has been clearly seen in patients with unilateral slipping in whom slipping on the contralateral side later developed (Figs. 5-A to 5-E). In several of these, roentgenograms of the other hip are available, which show changes developing long before the actual slipping. Occasionally roentgenograms made for other conditions, such as abdominal lesions, show involvement of the hip joints before clinical symptoms appear (Figs. 4-A to 4-J). These indicate that pathological changes may antedate symptoms or gross slipping. Failure on the part of the examining physician to make anteroposterior and lateral roentgenograms of any child with hip complaints, or to note the early metaphyseal changes, and the consequent failure to diagnose and treat the condition in its early stages, accounts for most of the severe displacements which later develop. Anteroposterior and particularly lateral roentgenograms should therefore be made routinely in all cases of hip complaints in children, and any metaphyseal changes should be noted.

PATIENTS TREATED BY CONSERVATIVE METHODS

Statistics

This series consists of twenty patients with twenty-three slipped capital femoral epiphyses treated conservatively. The average period of follow-up was six years. One of the hips in the group with bilateral involvement had been treated surgically and is therefore considered with the operative group. This leaves three patients with bilateral involvement treated conservatively and another in whom one hip was so treated.

Four of these patients were colored and sixteen were white. The average age at admission was eleven and one-half years for girls and thirteen years for boys. The oldest was fifteen and the youngest was nine years old. The average time between onset of symptoms and admission was six months. In any series, preponderance of any one ethnic group probably depends upon the neighborhood a hospital serves; the group studied includes a variety of nationalities.

All four patients with bilateral lesions were obese. Of the sixteen other patients, five were not obese or overweight. Four patients gave a history of trauma associated with onset of symptoms, sixteen did not. None had any other associated epiphyseal lesions. One patient had a cyst of the contralateral femur, which appeared to be neoplastic but later healed spontaneously. No relationship between this and other pathological conditions, childhood or otherwise, was noted in any of these patients. The number of right and left hips involved was the same.

* Read at the Annual Session of the American Medical Association, Section on Orthopaedic Surgery, San Francisco, California, June 28, 1950.

FIG. 1-A

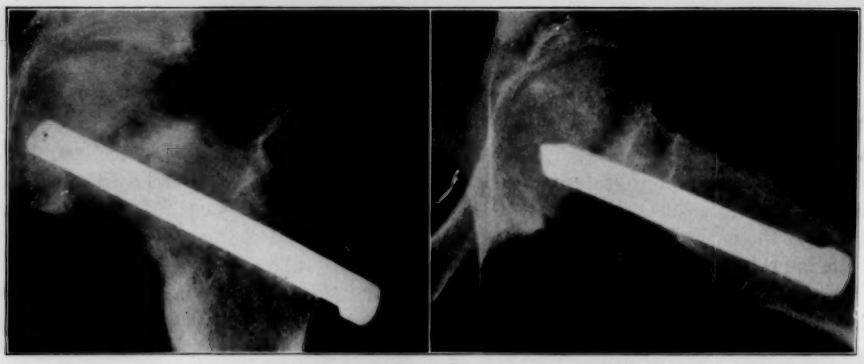

FIG. 1-B

FIG. 1-C

Slipped epiphysis with wedge osteotomy through the neck (leaving the epiphyseal cartilage intact) and nailing. Result excellent four years after operation.

This series of patients was treated conservatively at The House of St. Giles the Cripple during the period when the group treated by internal fixation was under treatment at St. Luke's Hospital. The orthopaedic personnel of St. Luke's Hospital was not at that time in charge of the professional work at St. Giles.

FIG. 2-A

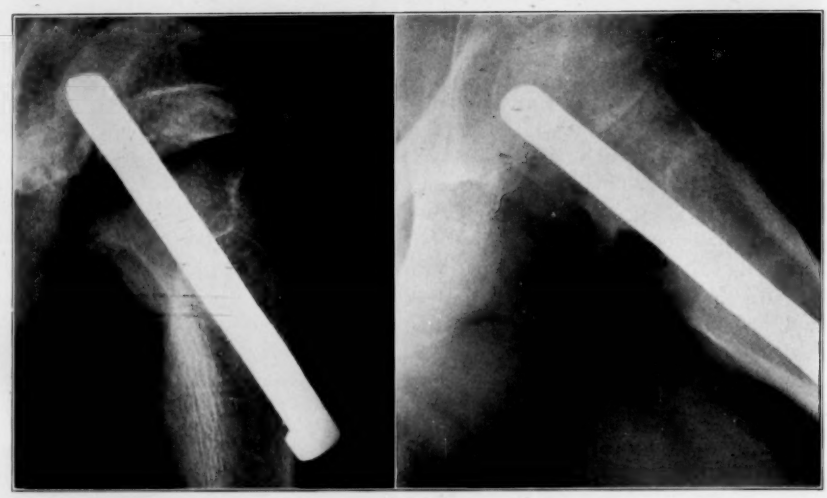

FIG. 2-B

Slipped epiphysis with wedge osteotomy through the neck (leaving the epiphyseal cartilage intact) and nailing in valgus.

Treatment

The usual method of treatment was to apply Russell traction for a month and a half, followed by crutch support for an average period of seven and one-half months. The acknowledged aim of traction was reduction of the displacement. In no instance was reduction accomplished by this means. Considerable atrophy was found to follow traction at times.

The longest period of non-weight-bearing with crutches was seventeen months. It is certain that, in many of these patients, the use of crutches did not prevent weight-bearing. A Sam Browne belt was ordered as a routine measure, but it was observed frequently that it was not worn. Slipping of the epiphysis of the contralateral femur developed in three of the four patients with bilateral involvement while they were bearing weight on crutches in order to protect the hip in which displacement had occurred first. It is probable that

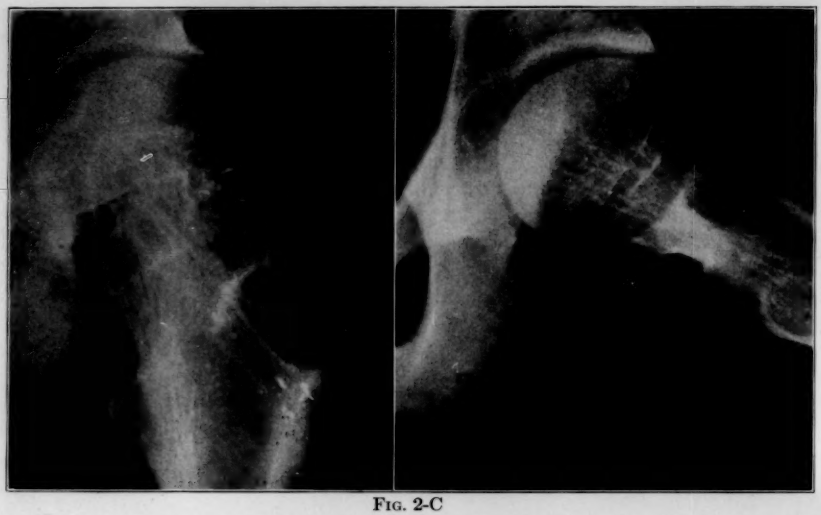

FIG. 2-C

Excellent result three years after operation.

excessive use of the second hip contributed to the displacement of the femoral epiphysis in that hip. In the fourth patient with bilateral slipping of the epiphysis, both femoral heads were found to be displaced on admission. None of the patients used braces.

In four patients manipulation under anaesthesia was attempted in an effort to reduce the displacement. This failed in all four cases. In these patients, it is interesting that roentgenograms show the presence of apparently productive changes; the lesion was probably old at the time when manipulation was attempted. As will be seen in the discussion of the second series, in cases with acute slipping reduction by manipulation has been accomplished. Plaster-spica fixation was used only in those patients on whom manipulation had been tried, and the average length of retention was two to three months. No benefit seemed to accrue from this fixation. All patients treated by manipulation and cast fixation had very poor results.

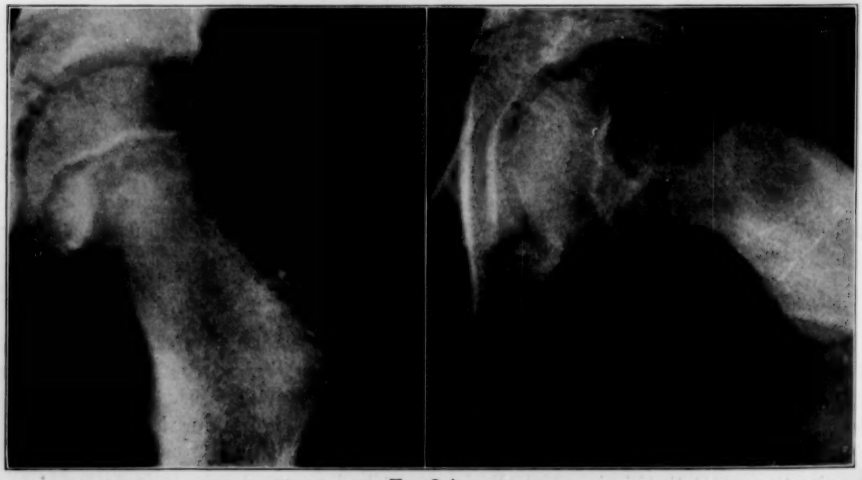

FIG. 3-A

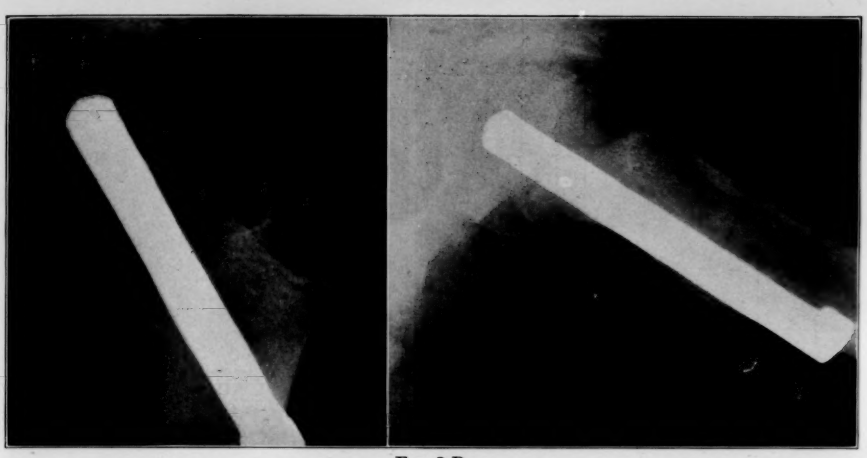

FIG. 3-B

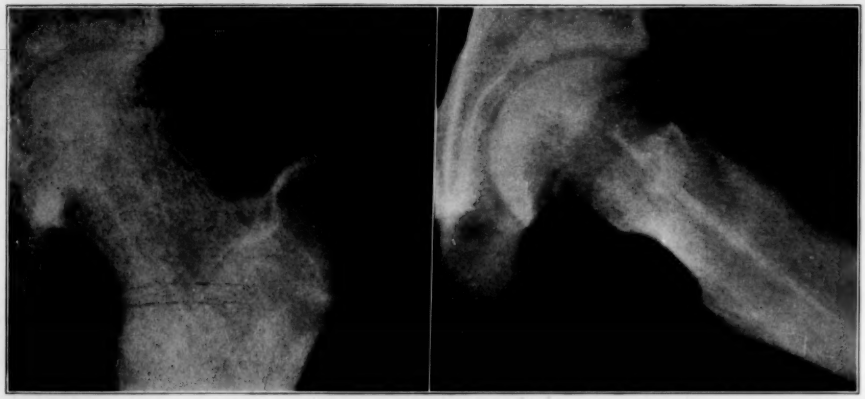

FIG. 3-C

Slipped epiphysis of minimal amount nailed without change in position, and excellent result four and a half years after operation.

In over half of the cases in which skin traction was used, it had to be removed because of skin irritation. No skeletal traction was used. Traction failed to secure reduction or to correct the external rotation of the extremity.

The period of hospitalization ranged from one to forty-eight months, with an average of 8.4 months. There were no deaths. The average time from onset of slipping and symptoms to closure of the epiphyseal line in these patients treated by conservative measures was 19.8 months.

Results

In the four bilateral cases in whom seven hips were treated conservatively, there were two clinically good, one fair, and four poor results. Among the sixteen patients treated conservatively for unilateral slipping of the femoral epiphysis, there were nine good, three fair, and four poor results.

A patient was considered to have a good result if there was very little restriction of motion, and if the hip was asymptomatic and showed no deformity. A result was consid-

FIG. 4-A

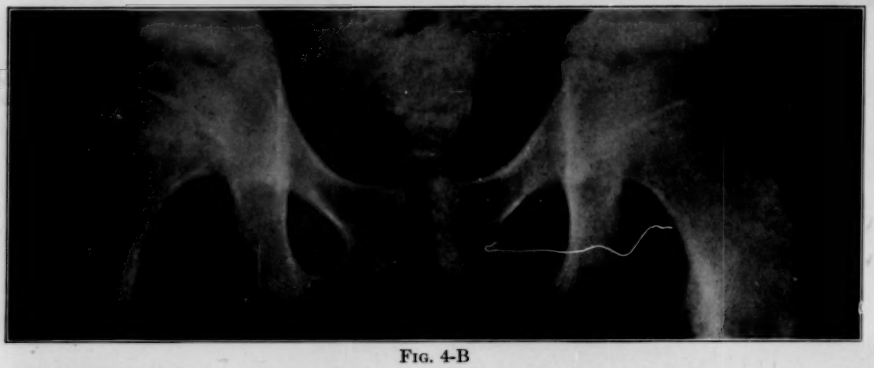

FIG. 4-B

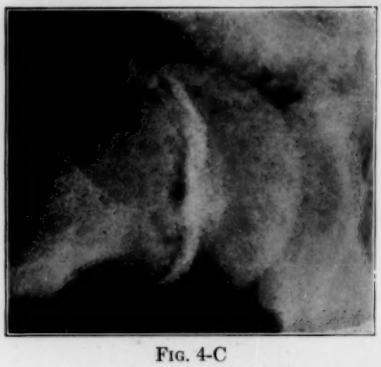

FIG. 4-C

Figs. 4-A to 4-J: Case No. 1112, F. H., St. Luke's chart No. A-106-123. In May 1945 an abdominal roentgenogram was made because the patient had a scrotal hematoma. No changes in the hips were noted at the time, but upon review of the plates later it was seen that pre-slipping of the right hip had existed. The boy remained fully active and without symptoms for another five months. By April of 1946, however, slipping had progressed so far that the hip had to be nailed.

In April 1946 irritative changes in the epiphysis of the left hip were noted. These changes progressed, but the patient remained asymptomatic until January 1947. All this time he was bearing weight on the right lower extremity, wearing a brace and using crutches. Symptoms on the left side began early in January 1947, and slipping of the capital femoral epiphysis thereafter grew rapidly worse, so that fixation with a nail was necessary.

This case represents two pre-slipping conditions: a pre-slipping stage in the right hip, unrecognized and without symptoms for a number of months, and later a pre-slipping condition in the left hip, also unnoted and asymptomatic for a number of months. Both times it was not until slipping had become considerable that symptoms first developed and clinical findings confirmed the condition.

Fig. 4-A: May 11, 1945. The changes present in the epiphysis of the right hip were not noted by us until a critical study of all cases of slipped femoral epiphyses was begun several years later.

The right hip had remained asymptomatic for five months after this roentgenogram was made, although the metaphyseal changes in the capital femoral epiphysis characteristic of the pre-slipping stage are clearly seen here.

Figs. 4-B and 4-C: April 30, 1946. In the anteroposterior view the right hip shows a slipping of the femoral epiphysis. The left hip shows irritative changes in the femoral metaphysis, indicating a pre-slipping stage. The right hip had not become symptomatic until six months previously when the patient had bruised it. The epiphyseal changes had been present eleven months before, — that is, at least five months before symptoms appeared.

At this time the left hip, which on the roentgenogram shows slight epiphyseal irritative changes, was entirely asymptomatic and remained so for eight and a half months longer. The lateral view, made on the same date with the hip in flexion, shows a considerable amount of slipping present on the right,

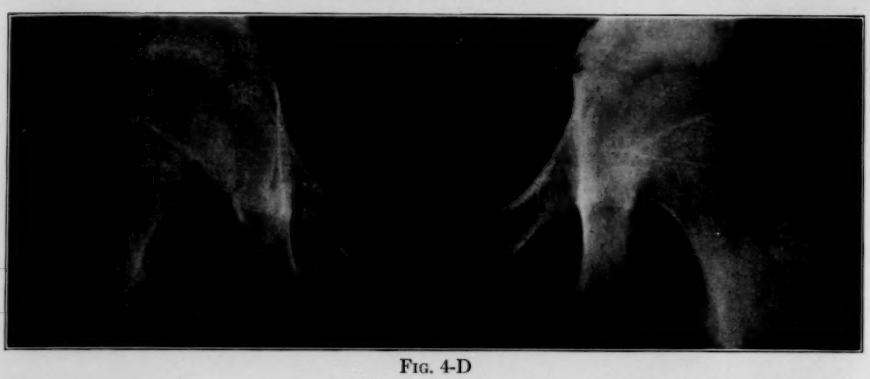

FIG. 4-D

FIG. 4-E

despite the slight amount of slipping which seems apparent in the anteroposterior view. This confirms the necessity for lateral views and critical evaluation of changes which may seem slight when the anteroposterior views are interpreted.

Fig. 4-D: May 20, 1946. This shows the marked increase in slipping which occurs sometimes in as short a period as three weeks, the interval between this and the previous x-ray. There was also a marked increase in symptoms and in clinical findings. In the left hip, which was still asymptomatic, further changes in the epiphyseal line seemed to occur within that three-week period, yet the left hip was still asymptomatic and remained asymptomatic for almost seven months longer.

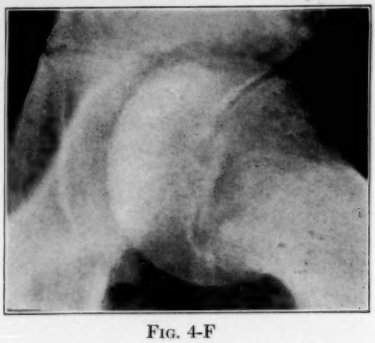

FIG. 4-F

Fig. 4-E: June 14, 1946. This shows replacement and nailing of slipped epiphysis on the right. The same irritative changes are present in the epiphysis on the left. The patient remained asymptomatic on the left and even carried on excessive weight-bearing on this side to protect the right hip for another six months, before gross slipping and symptoms began.

Fig. 4-F: January 16, 1947. The left hip at this time had been symptomatic for only one week. Though the metaphyseal changes in the anteroposterior view appeared milder than in previous x-rays, the lateral view now shows that slipping has occurred on the left.

ered to be fair if there was essentially 50 per cent. of motion or more, only occasional symptoms, and no fixed deformity. Results were considered to be poor if there was range of motion of less than 50 per cent., a fixed deformity, or continuous pain. Upon a review of the roentgenograms, it was interesting to note that the findings paralleled the clinical results. Traumatic arthritic changes due to incongruity of joint surfaces were a usual finding in the cases with poor results.

Of the total of twenty-three hips treated conservatively, there were eight poor results (34.78 per cent.), four fair results (17.39 per cent.) and only eleven good results (47.83 per cent.).

Shortening of the extremity was disregarded in evaluating the results. The average

FIG. 4-G

Fig. 4-G: January 16, 1947. The right hip has been nailed and is asymptomatic.

FIG. 4-H

FIG. 4-I FIG. 4-J

September 10, 1948. These show anteroposterior and lateral views of both previously slipped femoral epiphyses which had been treated by nailing. Closure of the epiphyseal lines was almost complete. At this time the patient was asymptomatic and had excellent hips.

amount of shortening was seven-eighths of an inch, the greatest being two inches, and the least, one-quarter inch. Shortening can, of course, be measured only in the cases with unilateral involvement.

Aseptic necrosis of the femoral head was noted in four cases, or 17.39 per cent. None of these four were patients in whom manipulation had been attempted and the condition gradually improved, the deformity being commensurate with the amount of aseptic necrosis present. Occasionally reconstruction of a badly damaged hip occurs spontaneously in younger patients after the bone structures have been molded, with absorption of protruding parts and production of new bone across the defect, so that a patient apparently on the way to a bad result achieves a fair or good result. Aseptic necrosis occasionally appears as an apparently sclerosing type, instead of the usual one of decalcification, atrophy, and softening of the metaphysis and epiphyseal bony structure.

The average result of conservative treatment, studied clinically and by roentgenogram, is one with shortening of approximately one inch, so that a lift must be added to the shoe, persistent coxa vara, an enlarged femoral head, an inadequate socket, some narrowing of the joint space, condensation changes in the bony socket by the age of twenty-one, hypertrophic changes developing in adult life, mild complaints of pain at times, and altered pelvic outline and inlet.

PATIENTS TREATED SURGICALLY

Statistics

This series consists of forty-one cases of slipping of the upper femoral epiphysis in thirty-seven patients. Five of the patients had bilateral involvement, but, as has been mentioned, one patient was treated conservatively for one hip, in which a good result was obtained before slipping occurred in the contralateral hip. Only the second case of slipping in this patient is therefore considered in this group.

The average time of follow-up was 4.1 years. All of these patients were white. There were twenty-three males and fourteen females. The average age at onset, given when the patients were first seen, was thirteen years and four months (fourteen years and four months in the males and eleven years and nine months in the females). The average period between the onset of symptoms (which indicates slipping) and the time of operation was six months. Of those patients with bilateral involvement, two were obese and three were of normal body structure. Of the thirty-two patients with unilateral involvement, thirteen were obese. No specific evidence of epiphyseal involvement other than the hip lesion was noted in any of the patients, nor was there any other pathological condition predisposing to a hip lesion. Twenty-five left hips and sixteen right hips were involved. A Smith-Petersen nail was used in all of these forty-one displaced upper femoral epiphyses.

Treatment

In five of our first patients, an open reduction was done, with division of the capsule, inspection of the slipping, and nailing under direct vision. Three achieved good results, one a fair, and one a poor result. In one of these patients the nail was driven across the joint line at the time of operation, but was retracted immediately and was later removed; this patient had an excellent result. In the patient with a poor result after open reduction, the nail had been driven through the joint and was not retracted for eight weeks. Ten years later she had marked limitation of motion, pain after prolonged activity, and some external rotation deformity. In one of these patients, the nailing was done retrograde through the head after dislocation, but the result was excellent. Retrograde nailing through the neck was done in another patient and the nail was driven back into the head during an open reduction. In this case the nail was also driven somewhat too far into the joint, and a later attempt to remove it did not succeed. This patient has had no trouble from the nail and twelve years after nailing had no symptoms, no shortening, and had an excellent

range of motion. In the last patient the nail was inserted laterally and the result was fair.

There were fourteen patients treated by wedge osteotomy of the neck of the femur. These included all of the patients with severe displacement of the epiphysis except the first five cases already mentioned above. Of these fourteen, twelve had good results, one a fair result, and one a poor result. There were no cases of non-union. Slight narrowing of the hip-joint space occurred in almost every case. Severe traumatic arthritis occurred in the patient with the poor result; a hip fusion was finally performed in this case.

One of these patients, who had bilateral slipping, had been treated elsewhere in 1944 and was treated conservatively for one year, during which time slipping occurred. By 1945 marked slipping had developed and he was severely crippled. Wedge osteotomy was done on each hip, two and one-half weeks apart, and an excellent final result was obtained.

If wedge osteotomy is done with good apposition and single insertion, results are uniformly good (Figs. 1-A to 1-C). Wedge osteotomy and nailing of the neck, even without

FIG. 5-A

FIG. 5-B

Figs. 5-A to 5-E: This boy, A. P. (our No. 1116), St. Luke's Hospital No. A 01785, is a patient who had rather acute slipping of the femoral epiphysis on the right. Changes appeared on the left and developed into definite slipping, although the patient remained asymptomatic and there were no clinical findings. Finally the slipped epiphysis on the left was nailed even though the patient was asymptomatic, because of the roentgenographic changes noted and the definite slipping which was taking place. This case proves, not only that a pre-slipping stage can exist without symptoms, but that actual and considerable slipping can take place and, if the slipping occurs slowly, the patient will still remain asymptomatic. For this reason we feel that, when symptoms appear suddenly, they indicate acute slipping. This may be a sudden increase in previous slight slipping, or sudden slipping of a previously irritated epiphysis (that is, an epiphysis in the pre-slipping stage).

Fig. 5-A: May 14, 1938. These x-rays were made when the boy was admitted to St. Luke's Hospital with pain in his right thigh of two months' duration. They show a slipped femoral epiphysis on the right, which was nailed nine days later. Irritative changes are present in the epiphysis on the left, and the head appears to be somewhat lower on the neck than it should be. Findings on the left were not noted in the x-rays at that time. As will be seen, the boy remained asymptomatic continuously thereafter while further slipping developed and even when definite slipping was present.

Fig. 5-B: X-rays dated May 25, 1939. This boy had had his right hip nailed on May 23, 1938; after this he used a brace and crutches until the nail was removed on March 27, 1939. The left hip was still completely asymptomatic although at this time it shows an increase in slipping since the previous x-ray, made May 14, 1938. He had no limp and made no complaint, although he was followed continuously in the clinic. He had been in the Hospital twice for his right hip and clinical findings were always negative on the left. The x-rays show the head displaced distally below the line of the neck on the left, as well as the typical metaphyseal changes.

FIG. 5-C

Fig. 5-C: Roentgenograms dated August 17, 1939. This is a lateral view of the left hip showing considerable slipping of the capital femoral epiphysis and typical irritative changes in the metaphysis. He was being seen in the clinic but even at this time, since he was asymptomatic and clinical findings were negative, it was not realized that the head might continue to displace. Three months later, November 6, 1939, Dr. Cleveland himself made a note that "the patient has partial slipping of the left upper femoral epiphysis. He is walking without pain or limp. The epiphysis is to be nailed as a precautionary measure. He might convert this into a complete slip."

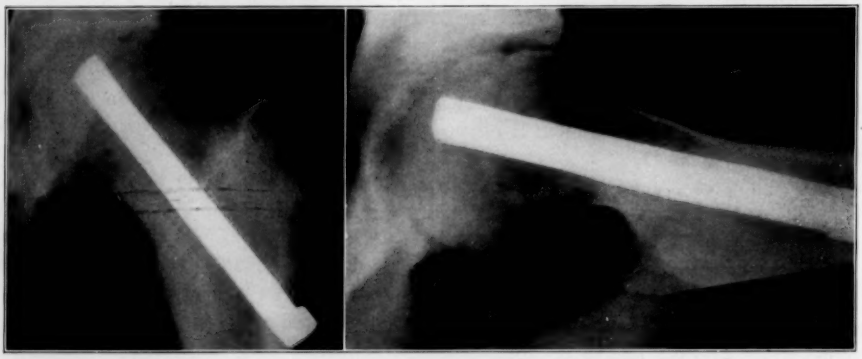

FIG. 5-D FIG. 5-E

Figs. 5-D and 5-E: X-rays dated April 27, 1940. Anteroposterior view of the left hip and lateral view of the hip in flexion, showing the nail across the slipped femoral epiphysis and closure of the epiphyseal line. The boy at this time had an excellent left hip and a good right hip.

close coaptation of surfaces (Figs. 2-A to 2-C), may result in an excellent hip if there has been good realignment of parts and no removal of any portion of the head. In cases where the epiphysis or a portion of the head or both, as well as a wedge of the neck, are removed, aseptic necrosis may occur. This accounted for the one poor result in the group of patients so treated.

The remaining twenty-two hips on which internal fixation was done must all be considered to have had some manipulation. Before a hip is nailed it is internally rotated, extended, and abducted. No strenuous attempt at actual reduction of the slipped capital femoral epiphysis was made. Despite this, reduction was obtained in four of these twenty-two hips. All four of these were cases with acute slipping, with sudden onset of completely incapacitating pain and marked displacement. There had been no prodromal symptoms in these patients.

No reductions were attempted in those cases in which slipping was not marked, or in

which slipping had been present for more than a few days. All of the four patients mentioned above had been incapacitated by a single accident occurring shortly before admission. In one the epiphysis was displaced as a result of a sudden twist while he was playing basketball, and he was sent to the hospital immediately. A second was seen within a week of the slipping; he had made a simple misstep while walking. In a third the capital femoral epiphysis slipped off while he was swinging with a bat, and he was seen at the hospital the same day. The fourth fell on the day of admission and was unable to get up. The longest interval between the accident and successful reduction by simple manipulation was therefore one week. Of these four patients with acute injuries in whom the slipping was easily reduced, three had poor results and only one secured a good result.

This brings up the question whether reduction by manipulation, together with application of a plaster-of-Paris spica for a period before nailing, would not be a preferable method in patients with sudden slipping after a single injury. That immediate surgical treatment may be contra-indicated in acute slipping of recent origin is demonstrated by another case. This patient had a sudden severe slipping following prodromal symptoms which were not heeded. Twenty pounds of Russell traction was applied for forty-eight hours without reducing the displacement. Open reduction and internal fixation was then done. Eighteen months after the injury there was density of the femoral head, suggesting aseptic necrosis.

In the eighteen remaining hips which were fixed internally, no replacement was secured, nor was any manipulation attempted (Figs. 3-A to 3-C). There was minimal displacement, and definite lytic changes at the metaphysis were noted. These were all promptly diagnosed and nailed immediately. Biplane roentgenographic study of the hip joint upon complaint forestalled serious displacement. Only one of these patients had a poor result. This was a case with more than minimal slipping; a wedge osteotomy should have been performed. It is evident, therefore, that in those cases in which slipping is so slight that replacement is unnecessary, fixation in position is the best surgical procedure.

The postoperative care consisted essentially of a short period of traction (usually ten days) until a hip brace could be secured to prevent external rotation. Weight-bearing on crutches was begun after that.

No deaths occurred. A superficial wound infection developed in one patient but the hip joint was not involved and the wound healed rapidly. A good result was obtained in this case. One patient had a bilateral postoperative thrombophlebitis from which he recovered. The average length of hospitalization for these surgically treated cases was twenty-nine days.

Results

In this series the results were as follows: thirty-three good (80.49 per cent.), one fair (2.44 per cent.), and seven poor (17.07 per cent.). The average patient with a good result had a hip which was clinically normal and, except for the nail or nail-tract scarring, appeared normal on the roentgenogram. The average amount of shortening was one-quarter inch. The greatest was five-eighths of an inch. The least represented a gain of one-quarter inch in the extremity.

There were six instances of aseptic necrosis in the operative series, or 14.63 per cent.

The tendency characteristic of very young patients toward realignment of the skeletal structure by molding was present in both series.

CONCLUSIONS

1. An early diagnosis by means of biplane roentgenograms and prompt treatment when hip complaints exist in the adolescent may prevent serious disability from severely displaced capital femoral epiphyses.

2. In slipping of the capital femoral epiphysis, when the deformity is not too great, simple nailing without reduction secures the best results.

3. In cases with acute slipping in which there is a definite trauma to account for the condition, the outlook may be poor and a waiting period after reduction may be necessary before internal fixation is undertaken.

4. Wedge osteotomy of the femoral neck for the more severe displacements in slipped femoral epiphyses presents an excellent outlook if the wedge is removed from the neck entirely, while the head and epiphyseal plate are left intact and a portion of the neck remains attached to the plate.

5. Aseptic necrosis of the femoral head occurred about equally in the series treated conservatively and the series treated by operative methods.

6. The outlook for securing a good or excellent result is greatly improved by the use of internal fixation.

THE DANGER OF EXPOSURE TO X-RAYS BY THE "BLIND-NAILING" TECHNIQUE

BY CHARLES A. ROWE, M.D., OAKLAND, CALIFORNIA

The purpose of this paper is to warn those doing hip-nailings by the "blind-nailing" technique of the danger of exposure to roentgen rays. The majority of techniques developed necessitate the taking of a lateral roentgenogram. Usually the surgeon or an assistant holds the cassette for the lateral film. The writer, realizing that repeated exposure to x-rays at close range is dangerous, performed an experiment to determine as accurately as possible the amount of roentgen-ray exposure a person receives while holding the x-ray cassette for the lateral view.

During a routine hip-nailing procedure, two 85-kilovolt, 15-milliampere x-ray machines were used. Five sets of films were required. The vertical projections did not require detectable radiation exposure to personnel, since the cassette was held in a holder beneath the operating table, and the operating team could move a safe distance from the patient. For the lateral view, the cassette was held each time by the same person. Three pocket dosimeters were placed on his body, and three film finger rings were placed on his fingers.

It was found that the person holding the cassette for the five lateral films received the following dosages of roentgen rays:

Body:	35 milliroentgens at the belt line,
	28 milliroentgens to the right side of the neck,
	4 milliroentgens to the left side of the chest.
Hands:	950 milliroentgens to the right ring finger,
	125 milliroentgens to the left ring finger,
	130 milliroentgens to the left forefinger.

The Atomic Energy Commission has recommended that 100 milliroentgens in any one day or a total of 300 milliroentgens in any one week is the maximum acceptable radiation which any one person should receive. From our experiment, it appears that the individual holding the lateral cassette is receiving three times the safety dose. The use of leaded gloves is not feasible, because of sterile technique; but, even with this precaution, not more than two films per day or eight films per week should be held by any one person. Recently there have been devised several mechanical lateral cassette holders. Any one of these can be used easily with sterile precautions, and it is recommended that those who do hip surgery frequently with the aid of x-ray should employ one of these devices.

SOME CLINICAL APPLICATIONS OF ERGOGRAPHY *

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No branch of medical practice is called upon more frequently than orthopaedics for the purpose of evaluating the magnitude and the functional significance of disabilities affecting the neuromuscular and skeletal systems. The merits of objectivity in disability evaluation are self-evident, especially when the evaluation is to be used in the adjudication of compensation claims due to industrial injuries or to injuries sustained during service in the armed forces. Such disability evaluation is usually based, as it should be, upon the judgment of the examining physician. Although no instrument can replace the knowledge, skill, and insight of the experienced observer, many of the basic components of physical demands and capacities analysis are amenable to direct measurement [5]. When these are appraised quantitatively, the objective evidence obtained serves as a valid and reliable guide to the examiner and lessens the burden of proof in much the same way that an electrocardiogram may be used to sustain the view of an internist.

The period since the onset of World War II has witnessed the evolution of what Rusk has aptly called the third phase of medical practice,—dynamic convalescent care which bridges the gap between the end of definitive treatment and the restoration of maximal residual function.[14] His concept has focused increasing attention on the social and economic advantages of utilizing remaining abilities for industrial purposes by the selective placement of impaired workers [2]. Before this can be done, facilities for, and techniques of treatment must be available for the full physical restoration of the disabled. This is the most important step in rehabilitation. Functional capacities must then be assessed in order to match a patient's abilities with the demands of the job assignment.

The ergograph (Fig. 1), which was first described by Mosso in 1890, is a simple device which records the range and quality of muscle contractions occurring during voluntary movements performed against resistance. Subsequently, it was introduced into this country by the physiologist Lombard; and, following World War I, it was used extensively in France by Amar for the vocational rehabilitation of the disabled.

When ergographic work is done repetitively at a rhythm set by a metronome, the successive muscle contractions are recorded and appear as an ergogram. This has diagnostic significance in the evaluation of five distinct aspects of functional capacity,—strength, power, work tolerance or endurance, skill, and range of movement (Fig. 2). The load lifted, the speed of movement, and the duration of exercise may be varied at will (Figs. 3-A and 3-B). The number of contractions performed and the distance through which the load has been moved are measured by appropriate indicating devices. The work done may then be computed by multiplying the load by the reading of the distance meter. Thus ergography yields two types of objective data,—it provides graphic records of the functional status of the subject and information necessary to reduce the findings to numerical values.

Ergography may be used for the following purposes: (1) to evaluate functional capacity at the onset of treatment; (2) to measure the progress of the patient under treatment aimed at restoration of function; (3) to measure the efficacy of different methods of management when comparative data are desired; (4) to indicate the end point of effective rehabilitation; and (5) to evaluate the magnitude of residual disability when the injury is such that full recovery is impossible.

* This work was done under contract with the Office of Naval Research (Project Nr 172 092). The technical assistance of Helen V. Skowlund, M.S., and Judith M. Blue, B.S., R.P.T., is gratefully acknowledged.

Modern ergographs are ink-writing, self-contained units amenable to use in any clinic. The technique of their operation is relatively simple; the interpretation of the findings, however, requires special knowledge. Work in progress at the Medical College of Virginia since 1946 [6,7,8] has led to the development of five reliable devices capable of measuring functional capacity in the execution of all major movements of the upper extremity, including rotation at the shoulder joint, pronation and supination, grip, and thumb opposition. These are among the most difficult natural movements to evaluate objectively. With a slight modification in the design of the lever to which the muscular force is applied, the same instruments may be used for the study of hip-joint and knee-joint movements.

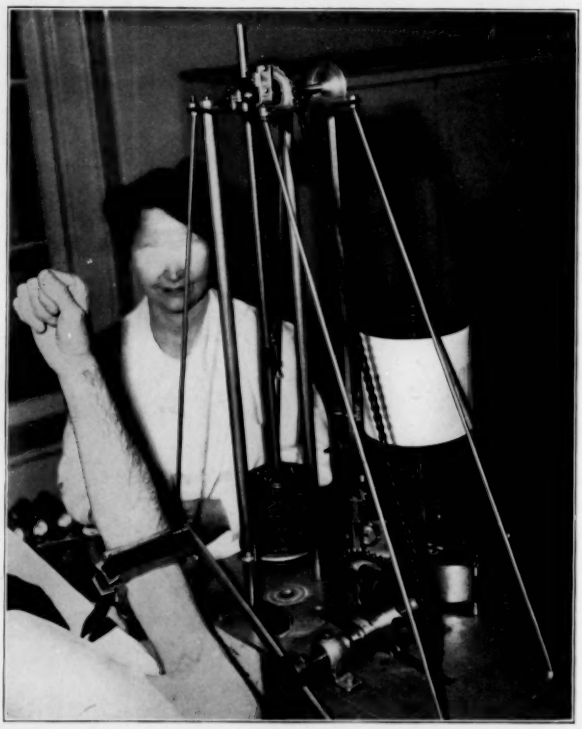

FIG. 1

Photograph of the shoulder ergograph. The force developed by the muscles under observation is applied to an axle which turns a wheel. Through the introduction of a load tower, this simple device is made to lift variable weights. Auxiliary indicating instruments permit the number of contractions and the distance through which the load has been moved to be measured. The extent and character of the contraction is recorded as an ergogram on the moving drum of a kymograph.

When the chief component of disability involves the performance of purposeful movements, ergography becomes a useful therapeutic and prognostic tool. Many precision tools initially used in the laboratory have proved advantageous when applied clinically. Ergography not only permits the precise gradation of the stress necessary to augment strength, power, and endurance, but allows at the same time the evaluation of functional status. The simplest and most reliable method of training and estimating work capacity by ergography is based on DeLorme's one-repetition maximum (1 R.M.)[3]. The rhythm in which the load is raised and lowered, the number of contractions per bout, and the rest pause between bouts are held constant. The load is the independent variable. It is increased by equal increments with each successive bout until the requisite number of contractions can no longer be performed at the assigned rhythm (Fig. 4). The work done per bout is then computed and graphed against time. A less satisfactory technique, also illustrated in Figure 4, is to hold both the load and the contraction-relaxation rate constant and to accept the duration of exercise in a single bout as the independent variable. To use this method satisfactorily, the load must be accurately selected so that the end point of functional capacity is reached without the development of a fatigue level. Failure to assign a load heavy enough to produce complete fatigue without a leveling off subjects the performance to stereotyping and boredom, which adversely affects the reliability of the procedure. This test is less conducive to the attainment of a reliable all-out effort than that in which the exercise is done in short repetitive bouts. Because the

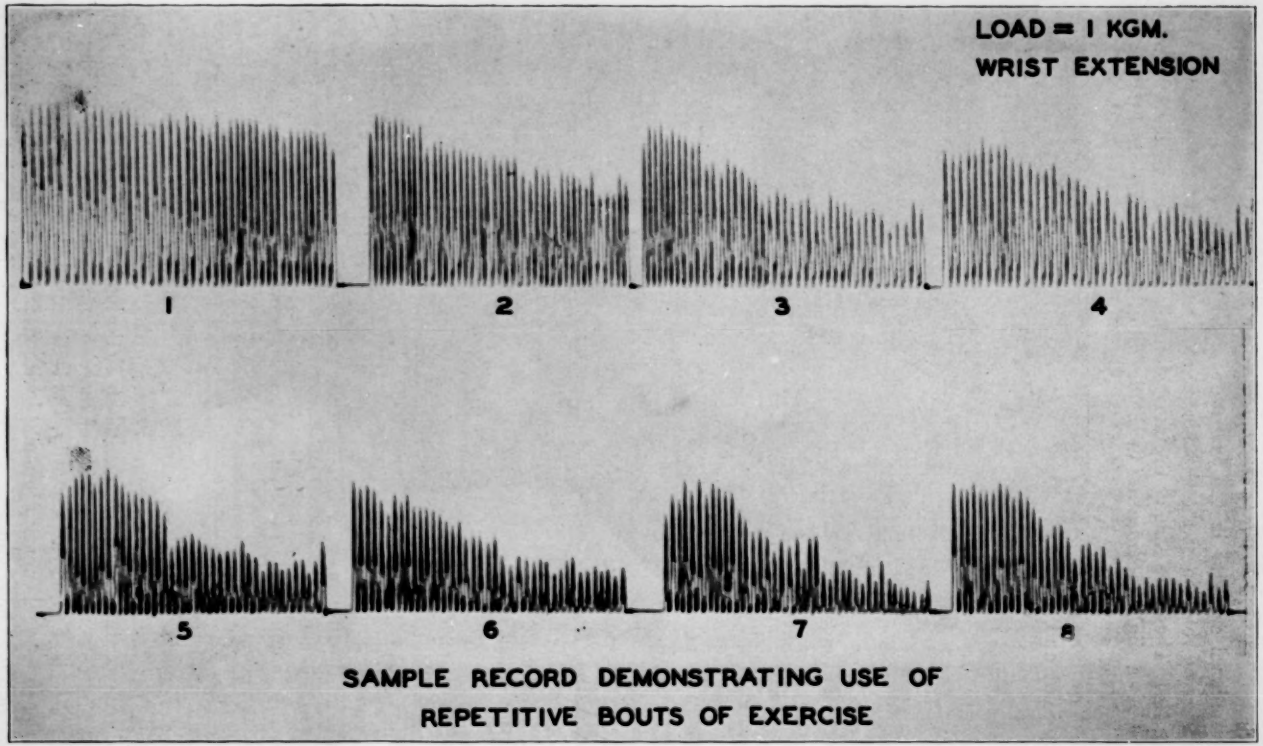

FIG. 2

An illustrative normal record demonstrating how functional capacity may be rendered objective. When the work done per bout is graphed against time, a fatigue curve results.

fatigue of volitional effort is usually central and not peripheral, psychogenic factors must be considered in the selection of the procedure.

The curve of work yielded by application of the limit-day procedure * serves several

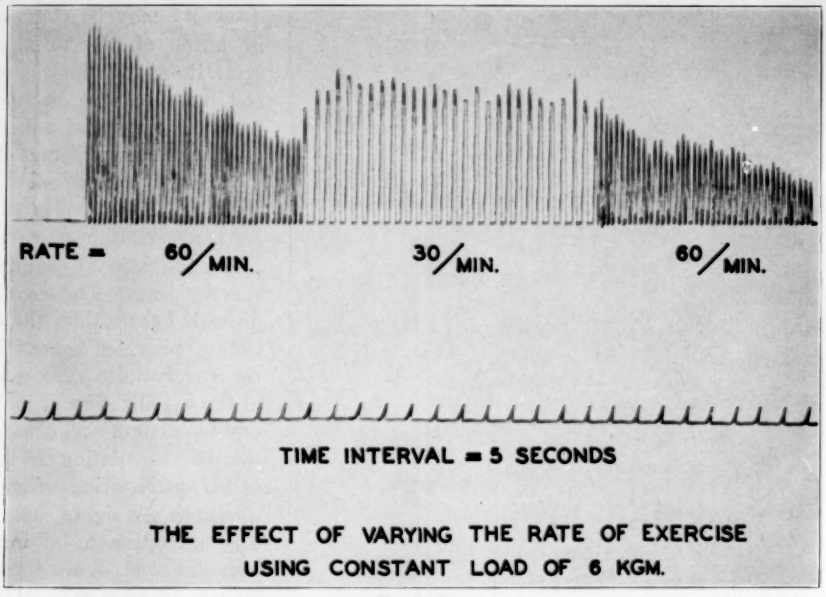

FIG. 3-A

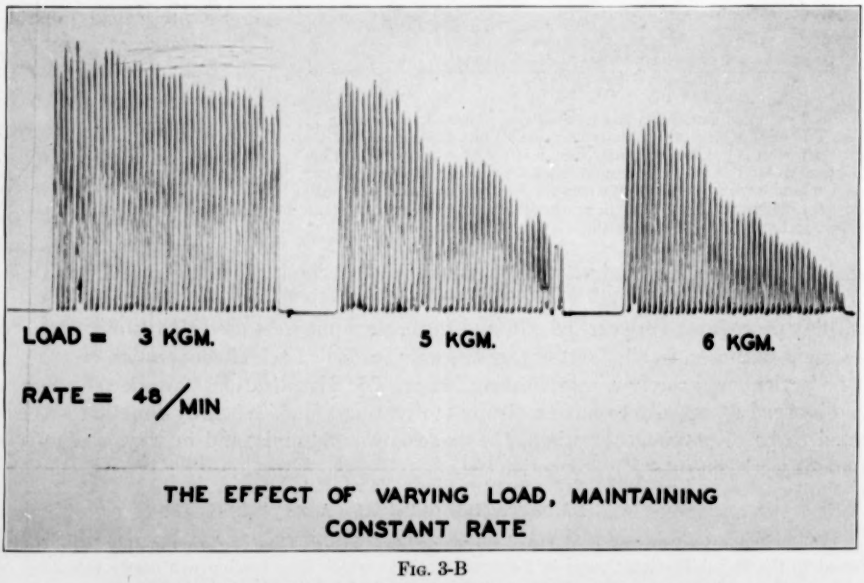

FIG. 3-B

Normal records illustrating the influence of load and speed on work output.

* A term used by the authors to designate a procedure identical in principle with DeLorme's one-repetition maximum (1 R.M.). The authors' procedure differs from DeLorme's in that he permits fewer and fewer contractions, keeping the range of movement constant, while the authors allow the range of movement to decrease, keeping the total number of trials per bout constant.

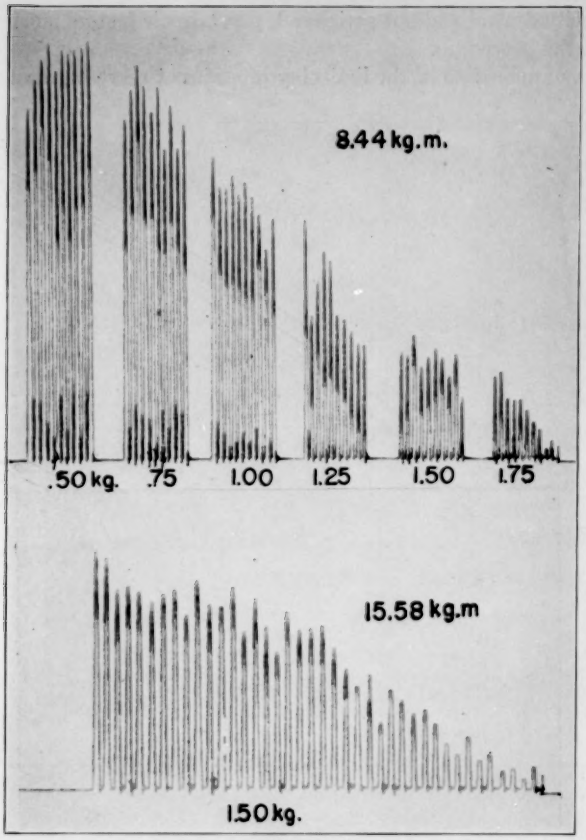

FIG. 4

Normal record, illustrating the response to progressive increase in stress. The load is the independent variable. When the functional capacity per bout is graphed against time, a curve of work results. This indicates the load at which optimum work may be done. In the lower record, a load beyond the optimum and the contraction-relaxation rate were held constant. The duration of the effort was the independent variable in terms of which work capacity may be measured.

functions. When the ergograph is used to test both arms in the presence of a unilateral injury or disease, the disability may be evaluated in terms of the uninjured arm. Re-applications of the test measure progress under treatment, the end point of effective therapy, and the magnitude of residual dysfunction. The curve of work *per se* also contains data useful for the rational grading of exercise dosage. The selection of loads lighter than the optimum provides exercise of the steady-state type useful in the mobilization of joints, development of skill, stimulation of circulation locally, and augmentation of work tolerance. Weights heavier than the optimum fall in the overload zone. When the objective of treatment is the development of strength, the exercise prescribed must be of this intensity.[4]

To demonstrate how ergography can be used to appraise disability, to improve functional capacity, and to judge progress, observations were made on forty-six patients,—twenty males and twenty-six females. The majority of these were in the second, third, and fourth decades of life. A wide variety of disabling conditions was surveyed. Three hundred and twenty-two limit-day procedures were carried out, and the ergographs were used eighty-nine times for treatment purposes. In all, 3,621 ergograms were studied. Lack of cooperation on the part of the patient was rarely a complicating factor. The visualization of work achievement was observed repeatedly to have a strong motivating value. When dysfunction was suspected to be of psychogenic origin, the exercise was administered in ways designed to augment work output by reflex action [10,11].

ILLUSTRATIVE CLINICAL CASES

A. H., a boy, seventeen years old, sustained severe burns in a gasoline explosion in July 1946. He was referred to the Rehabilitation Center in February 1947, at which time healing was nearly complete. No exercise had been administered either for the mobilization of the joints involved, the maintenance of strength, or the prevention of contractures. Physical medicine at first consisted of massage, passive and active-assistive exercises, and stretching. Pulley exercises were added subsequently. He was not seen in the disability evaluation laboratory until the day of discharge, at which time he was considered to have attained the end point of definitive treatment in the judgment of the responsible physician. Permission was granted to continue

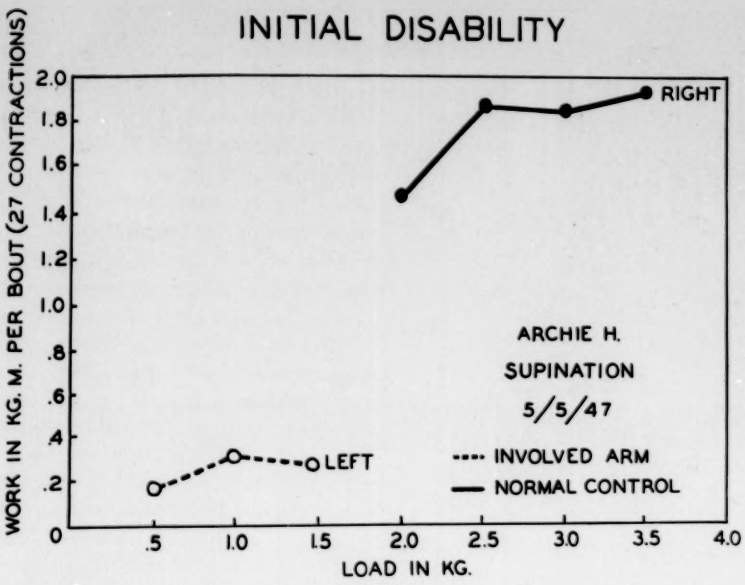

FIG. 5-A

Work-capacity test, indicating the degree of disability of a patient who had apparently reached the end point of effective rehabilitation by subjective evaluation.

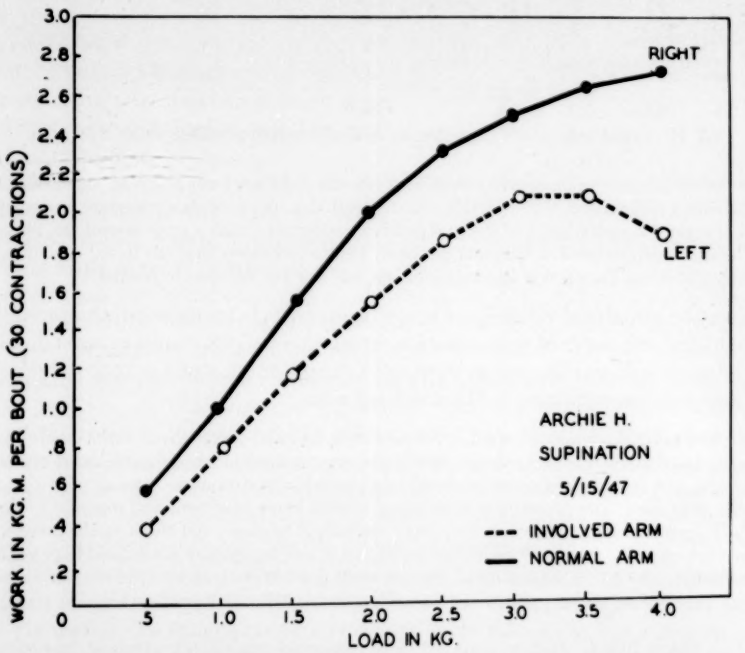

FIG. 5-B

Demonstrates residual disability after ten days of ergographic exercise under progressively increasing resistance.

observations for ten days. Figure 5-A shows the magnitude of the initial disability in a single movement, supination. The patient, who was intelligent, interested, and cooperative, exercised daily on the radio-ulnar

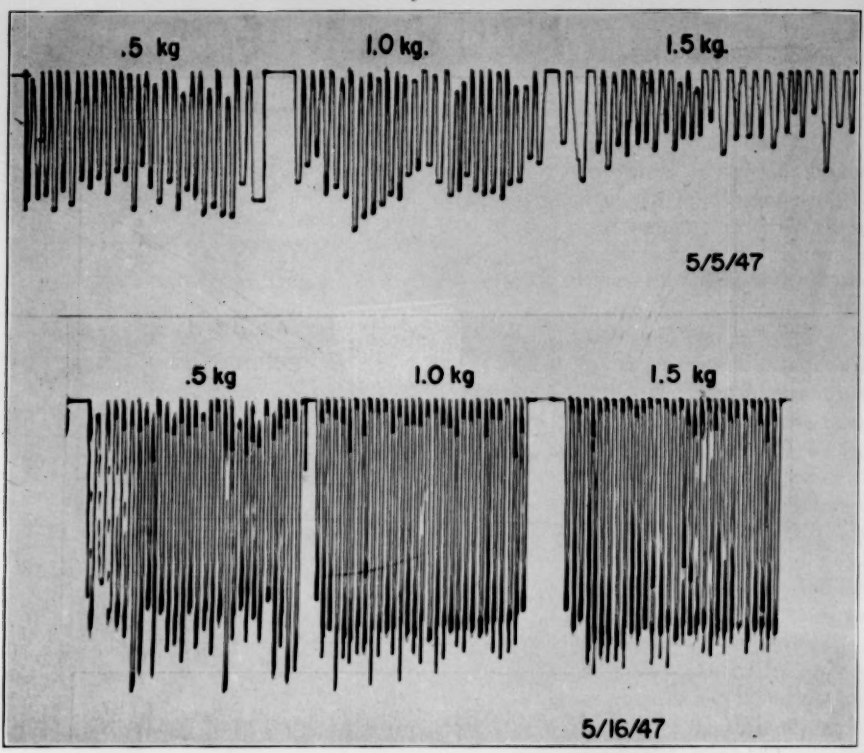

FIG. 6

A. H.: Ergograms presenting objective evidence of improvement under treatment.

ergograph, working against progressively increasing resistance. Figure 6 demonstrates significant augmentation in the extent and rhythm of contraction. On the tenth day, the limit-day procedure was repeated. This consisted of eight successive bouts of thirty repetitive contractions with a sixty-second rest pause between bouts. The load was increased .5 kilogram per bout. Figure 5-B shows that the initial disability had been significantly alleviated. Supination approximated but had not yet returned to normal.

When the functional capacity of homologous parts is unimpaired, the ascending limb of the right and left curve of work coincide, irrespective of differences in hand dominance [9]. These differences do not become evident until the optimum stress is approached, and then magnify as exercise continues in the overload zone.

W. G. had suffered a gunshot wound in the neck with brachial plexus involvement approximately one year prior to the time he was first seen for testing purposes. A manual muscle test showed weakness of the biceps, triceps, and deltoid. Supination was markedly impaired; pronation was rated as fair; wrist and finger movements were good. The patient was undergoing routine home treatment and reported to the Physical Medicine Department once weekly for short-wave diathermy, massage, and check on the exercise program. The three work-capacity tests included in Figure 7 illustrate how ergography can be used to evaluate progress under treatment. The gain in supination of the first week was 140 per cent.; that of the third week, 642 per cent. Work capacity improved from 33.81 kilogram-meters to 250.92 kilogram-meters.

C. J., a college junior, nineteen years old, with congenital quadriplegic athetosis, was referred to the Physical Medicine Department by the State Division of Vocational Rehabilitation. There was minimum disability in the legs. Involvement of the left arm was moderately severe and that of the right was slight. For approximately one month he performed ergographic exercise of the supinators and wrist-joint extensors, three times weekly, executing ten bouts of forty repetitive contractions with each muscle group, or a total of 1,600 contractions per treatment period, against progressively increasing resistance. His subjective reactions included a conviction that the exercise had a steadying effect so that his power of grasping and

releasing with the right hand, his major disability, improved. He thought he wrote faster but no more legibly.

Figure 8-A shows a random record obtained during the course of treatment. For purposes of comparison, an illustrative ergogram from the records of a much more severely involved sixteen-year-old athetoid quadriplegic patient, R. S., is included in the same Figure. It was more difficult for C. J. to lower the weight slowly than to raise it, and relaxation was sometimes incomplete, especially early in the exercise period (ergograms 1 and 2). Disability was less marked when exercise with heavier loads called forth a more nearly maximum volitional innervation (ergograms 9 and 10,—the last two of a daily series).

The training curve resulting from sixteen treatment days in one month is reproduced in Figure 8-B. The slope gradient of the improvement curve in supination rose more sharply than that for wrist extension, and reached its peak about midway in the period of observation. This might well be considered the end point of effective treatment. The precipitous diminution in functional capacity on July 28 and 30 is attributable to adverse environmental conditions, affecting temperature regulation. Thus, hot and humid weather may make dysfunction more acute.

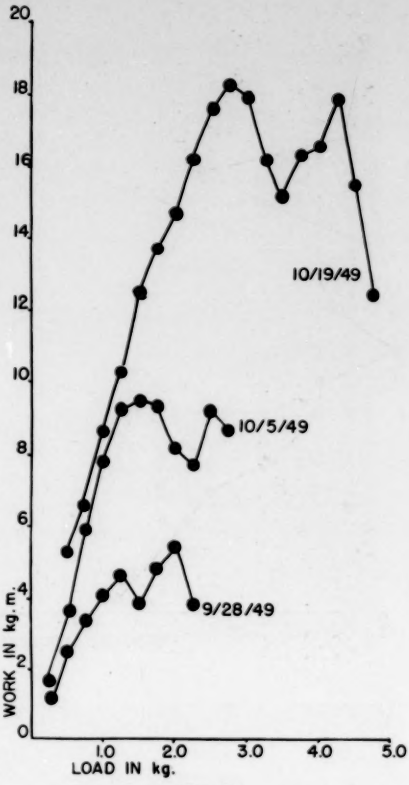

FIG. 7

W. G.: Curves of work computed from limit-day-test data, showing progress under treatment.

Figures 9-A through 10-B illustrate the diagnostic significance of the ergogram itself. The three examples in Figure 9-A demonstrate the limbering up which characterizes the initial efforts of patients with arthritis.

An interesting incidental observation was made on C. C., a young adult male with rheumatoid spondylitis. He had no limitation in shoulder-joint motion and was used in tests designed to validate the shoulder ergograph. Abduction was performed with the patient lying on his side; flexion, extension, medial and lateral rotation were tested in the supine position. It was observed repeatedly that, whereas kyphosis was so pronounced at the onset of testing that the patient could not place his head on the plinth, repetitive exercise on the shoulder ergograph, performed against heavy resistance, indirectly affected the functional deformity of the vertebral column to such a degree that an essentially normal supine position was attained before the exercise period had ended. The patient walked with an erect posture following treatment.

Many observations were made on patients suffering from multiple sclerosis. These demonstrated a highly characteristic abnormality in the ergographic fatigue curve, illustrated in Figure 9-B. As fatigue became more and more evident in the course of a series of repetitive bouts, the patient lost the ability to grade the intensity of the effort; and the extent and rhythm of successive contractions became increasingly irregular. In the severely involved, impairment of skill in the execution of movement accompanied fatigue.

J. S., a girl, thirteen years old, was admitted to St. Philip Hospital with a chief complaint of pain and swelling in the right wrist, which had developed suddenly two weeks before admission. The wrist and elbow joints were exquisitely painful on attempted motion, and the fingers could not be moved voluntarily. The

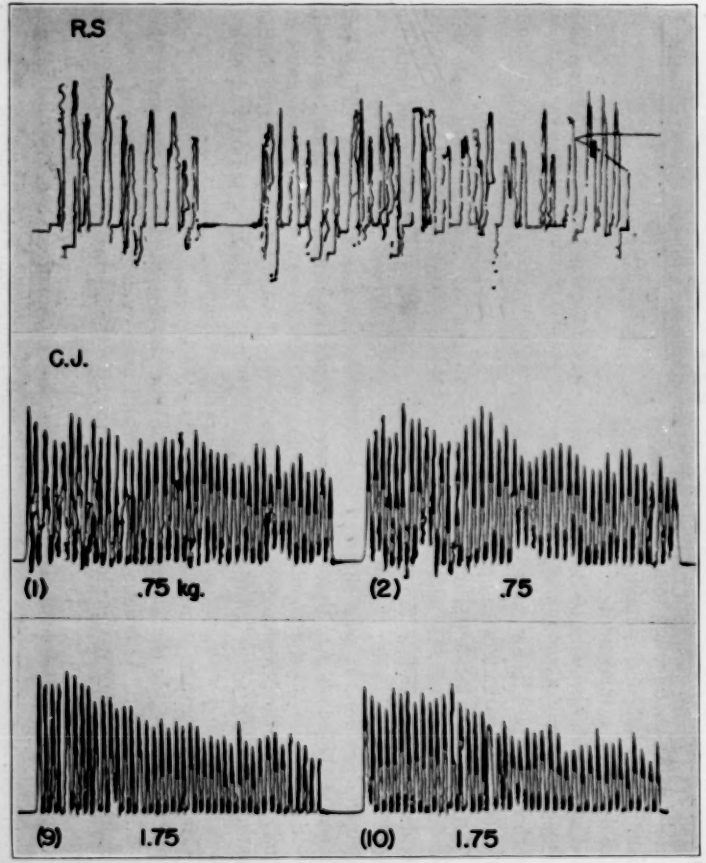

FIG. 8-A

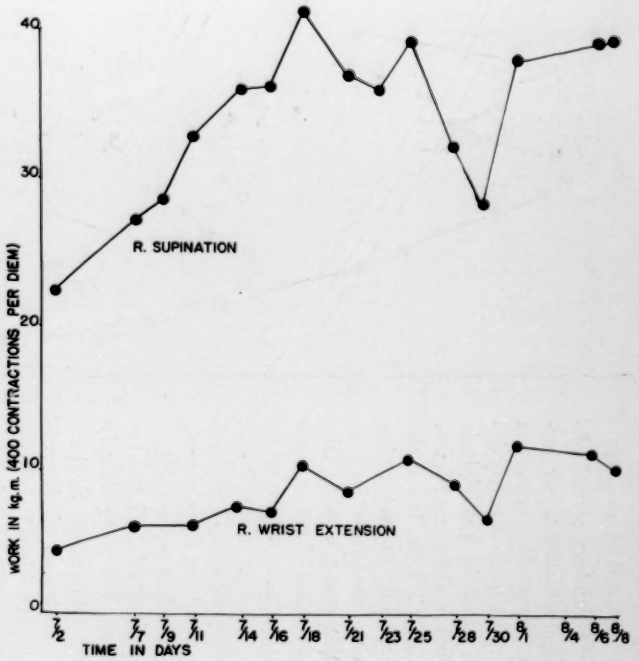

FIG. 8-B

Fig. 8-A: Comparison of two degrees of athetosis and the steadying influence of an increased load.

Fig. 8-B: Training curve of C. J. showing the influence of inclement weather, the difference in the slope gradient of improvement of two muscle groups, and the end point of effective treatment.

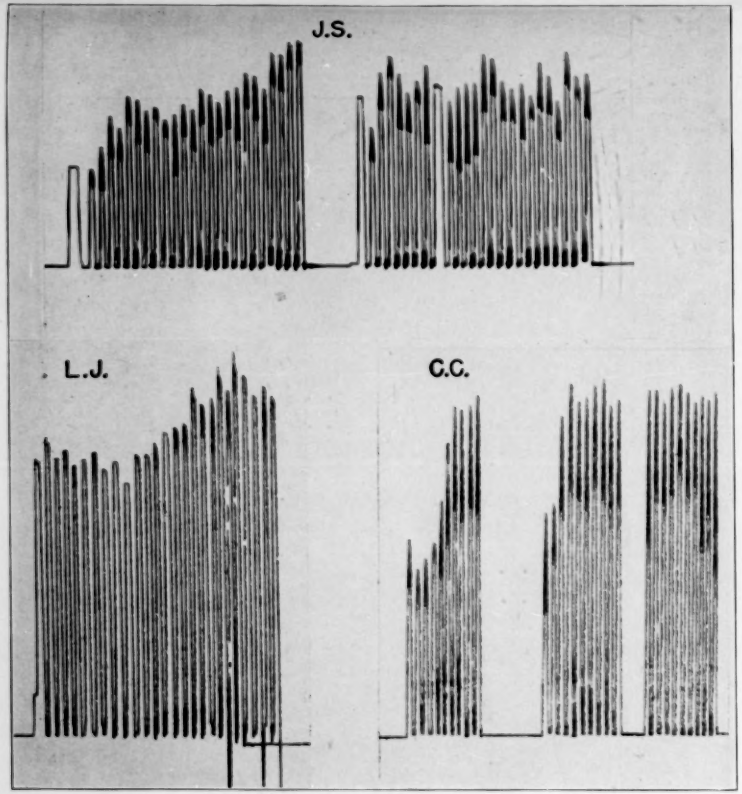

FIG. 9-A

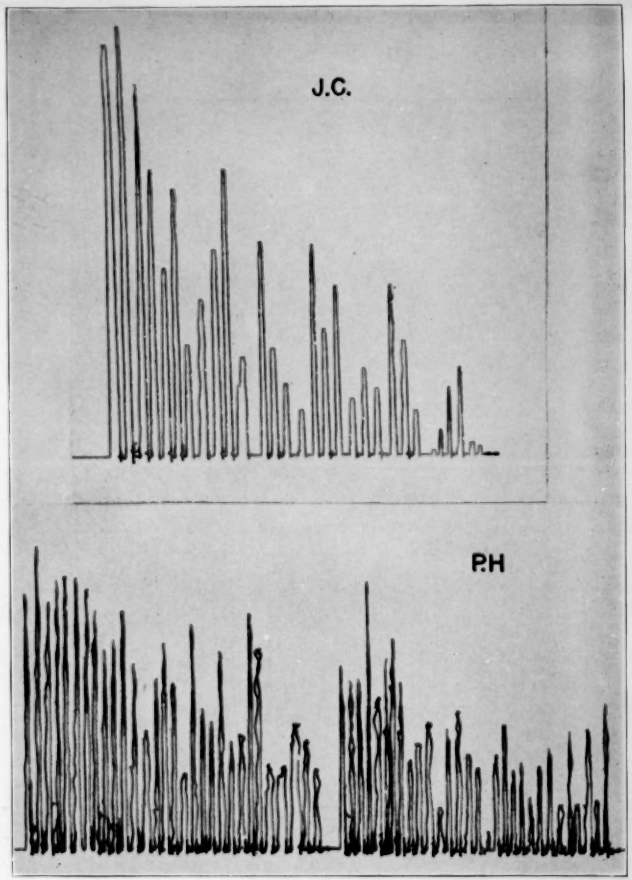

FIG. 9-B

Fig. 9-A: The three examples demonstrate the limbering up at the onset of exercise, characteristic of the initial efforts of patients with arthritis. J. S.: wrist extension; L. J.: supination; C. C.: shoulder abduction.

Fig. 9-B: Terminal ergograms of two patients with multiple sclerosis showing characteristic inability to grade repetitive contractions.

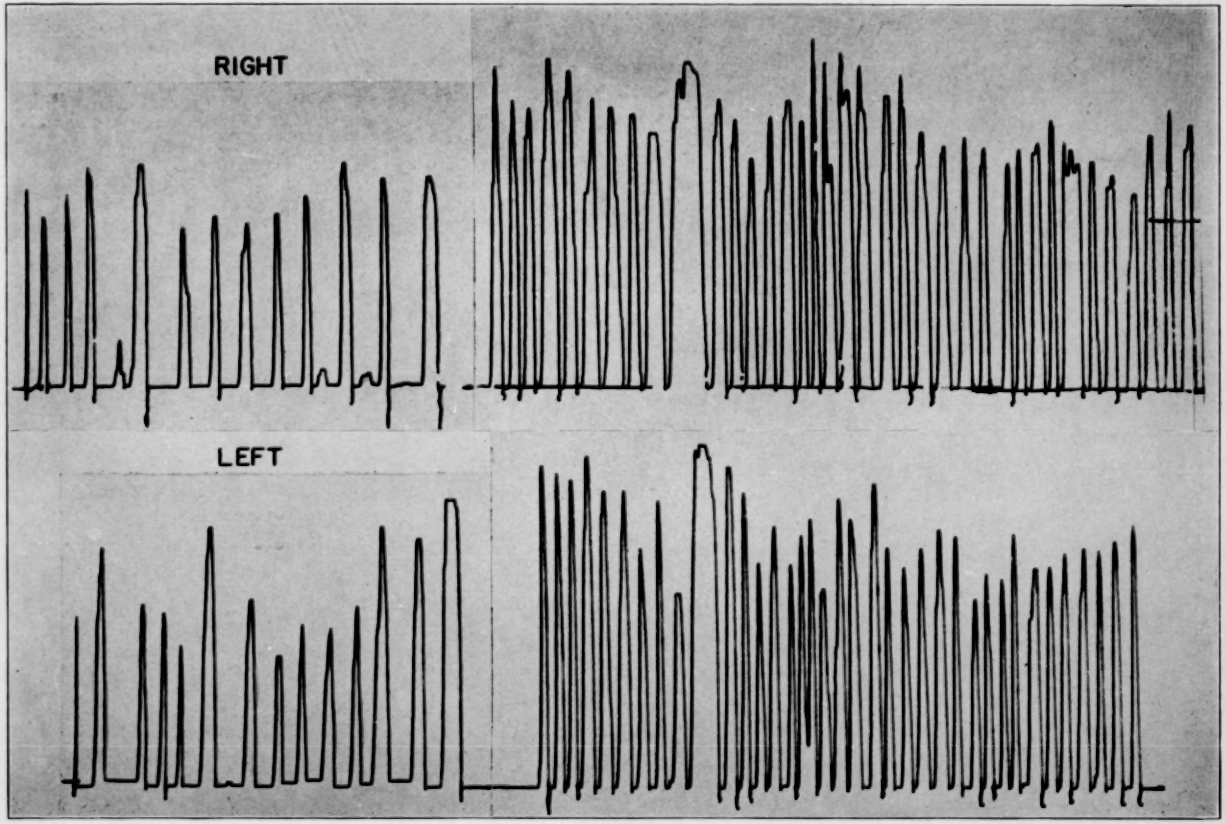

FIG. 10-A

Fig. 10-A: Bimanual wrist extension of a patient with spastic quadriplegia showing improvement in the extent and speed of contraction during a single treatment period.

Fig. 10-B: Wrist abduction in a patient with specific arthritis, showing that previous activity facilitates performance.

Fig. 10-B: Wrist abduction in a patient with specific arthritis, showing that previous activity facilitates performance.

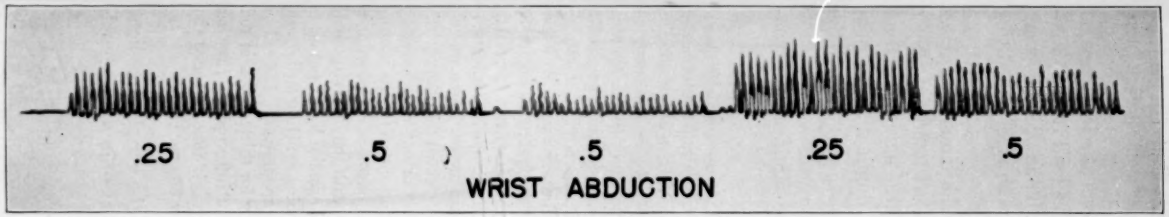

FIG. 10-B

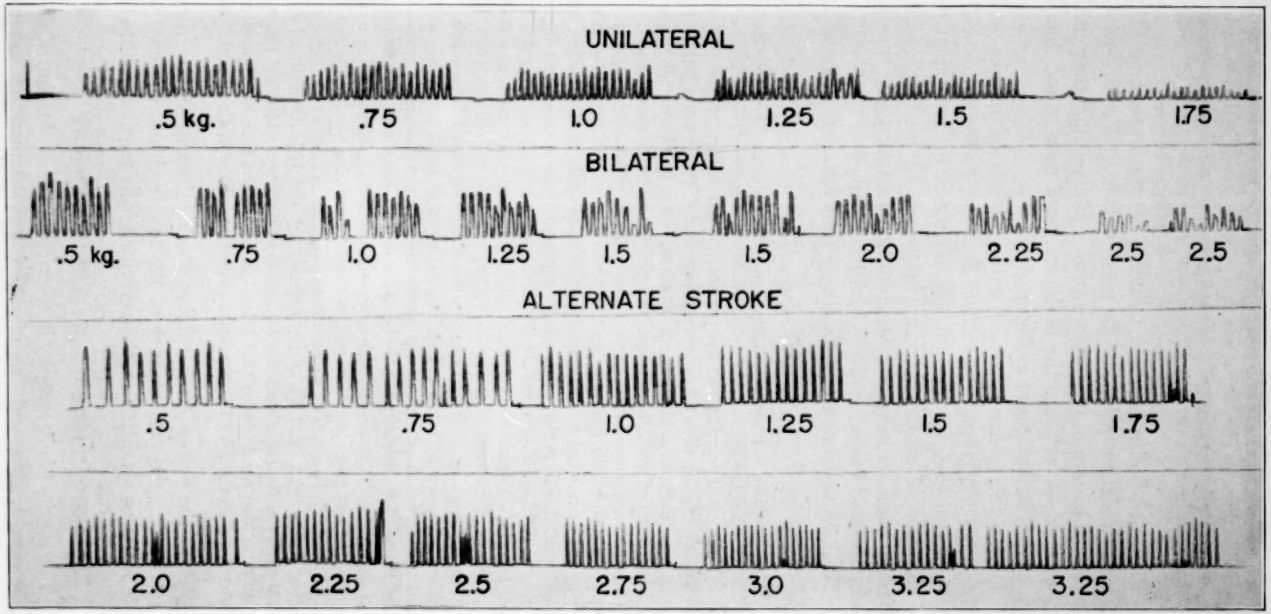

FIG. 11 (see page 980)

Fig. 11: Ergograms illustrating how work output was increased reflexively in a patient with an unilateral lesion who was suspected of malingering. Co-contraction of homologous muscle groups of the injured and the normal side, or their alternate contraction, automatically increased the functional capacity of the disabled side.

condition was diagnosed as acute gonorrheal arthritis. Systemic manifestations subsided under sulfonamide and penicillin therapy. The patient was then referred to the Physical Medicine Department because of a progressive decrease in the range of motion. Ergographic exercise was used for the mobilization of the joints involved and to increase strength. Lack of motivation on the part of the patient was a complicating problem.

Figure 10-B illustrates the influence of exercise in the overload zone at a level beyond which the assigned task could be performed easily. Upon reducing the load from .5 kilogram to .25 kilogram, much more work could be done than initially. Thus previous work may be used to facilitate the performance of more work. Another method of expediting work output is illustrated in Figure 10-A.

J. B., a girl, twelve years old, with spastic quadriplegia, performed bimanual exercises on the wrist ergograph. The initial effort was slow and labored. The left hand did 82 per cent. as much work as the right. By the end of the treatment period, the extent, rhythm, and duration of contraction had increased. Co-contraction of the dominant and non-preferred hand so increased the functional capacity of the latter that it exceeded the dominant hand in performance by 10 per cent.

We have demonstrated elsewhere that bilateral exercise may be significantly dynamogenic [10].

M. B. sustained a transverse laceration of the palm and multiple fractures of the metacarpals when a window fell upon the left hand. The part involved was immobilized for one month. The soft tissues healed with a minimum of scarring, but the patient complained of pain and stiffness in the fingers and wrist. The hand was held rigidly with the fingers partially flexed. Passive manipulation of the wrist joint demonstrated no limitation in motion. The fingers, however, could be neither fully extended nor fully flexed. Routine physical treatment was administered. This consisted of whirlpool therapy, massage, and active and passive stretching. Progress was satisfactory. Treatment was discontinued, and the patient was advised to resume light work. He continued to complain that he could not use the hand because of stiffness and pain. Six weeks later he was re-referred to the Clinic for disability evaluation. The first series of ergograms in Figure 11 demonstrate M. B.'s performance on the grip ergograph when contracting against progressively increasing resistance. Total work done was .74 kilogram-meter. The second and third trials were similar, .77 kilogram-meter and .55 kilogram-meter respectively. The mean work done was .69 kilogram-meter. There was no evidence of improvement with repeated testing, which is in itself abnormal. It was suspected that the patient might be malingering. Bilateral exercise was then introduced to determine whether or not work capacity could be augmented by reflex action. The patient was urged to put his undivided attention on the contralateral uninvolved hand, which was given the task of maintaining pressure in a pneumatic system at a predetermined level indicated on a dial. Although he sometimes forgot to contract with the involved hand, the total work done on the left side exceeded that accomplished during unilateral exercise by 84 per cent. After a short rest pause, exercise was resumed, alternating strokes instead of gripping synchronously with the right and left hands. The acceleration in rhythm evident in the ergogram was spontaneous. Instead of stopping on the tenth bout, the goal previously set, the patient continued exercising for thirteen bouts; and then terminated the experiment by contracting thirty-two additional times without interruption, carrying a maximum load nearly twice that tolerated during the unilateral exercise. The work done exceeded the unilateral performance by 763 per cent., and exceeded the bilateral performance by 369 per cent.

Thus, the power of contraction was significantly augmented by the simple expedient of alternating the performance of the involved and the contralateral uninvolved hand, while focusing attention on the activity of the normal hand.

SUMMARY

The merits of ergography in relation to the evaluation of disability, the quantification of exercise dosage, and the objective measurement of progress should be considered. Ergography may be useful as a guide to the medical examiner in the evaluation of the functional status of the orthopaedically disabled at the onset of treatment, the critical appraisal of end results, the determination of the end point of effective rehabilitation, and the magnitude of residual dysfunction. Although adequate management of the patient

usually requires no specialized techniques to evaluate functional status, high degrees of precision in measurement are sometimes desired. Objective testing then has special merit; it enables the examiner to support his deductions with demonstrable evidence.

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ARTHRODESIS OF THE KNEE

A Comparison of the Compression Method with the Non-Compression Method*

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Arthrodesis of the knee joint for the relief of painful conditions caused by disease and deformity has been used by orthopaedic surgeons for many years. Indications for this ankylosing procedure are well known; however, techniques for performing it have not yet been standardized and the results are not well correlated.

One of the earliest attempts to devise a rational method for securing early arthrodesis of the diseased knee joint was made by Hibbs in January 1909; in 1911, he reported the technique which now bears his name. In 1932, Key advocated a compression principle for arthrodesis of the knee, but it was not until recently that reports of encouraging results

TABLE I

Indications for Arthrodesis of the Knee

Indications	Compression	Non-Compression	Total
Tuberculosis	5	4	9
Neuropathic joints	1	2	3
Congenital deformity and acquired arthritis	2	3	5
Flail knee caused by poliomyelitis	0	2	2
Traumatic arthritis	1	1	2
Hypertrophic arthritis	2	3	5
Suppurative arthritis	1	6	7
Rheumatoid arthritis	0	3	3
Total	12	24	36

through its use have appeared. Charnley, in 1948, reported good results in fifteen cases of arthrodesis in which this compression principle was employed; Eggers, in the same year, reported the successful use of the compression principle in clinical as well as experimental cases of fractures. About the same time appeared Chapchal's report of the use of this principle by means of an intramedullary nail and early weight-bearing in six cases with excellent results.

During the past ten years on the Tulane Orthopaedic Service at Charity Hospital in New Orleans and in the Department of Orthopaedics, Ochsner Clinic, arthrodesis of the knee has been performed thirty-six times. Thirty-four patients have been followed closely enough to evaluate the results. Prior to July 1948, a variety of techniques had been used. However, because of the encouraging results reported in the literature with the compression principle, we have used this technique exclusively in our last twelve cases. For the convenience of discussion, the cases have been divided into non-compression cases (twenty-four patients) and compression cases (twelve patients). Indications for the procedure are shown in Table I.

In the non-compression group, a variety of techniques was employed, the most popular of which was erasion of the joint, followed by internal fixation with two crossed

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 30, 1951.

Steinmann pins. The various techniques employed in this group are shown in Table II.

Postoperative care in the non-compression group varied considerably, but in general a single plaster hip spica was applied for about six to eight weeks, followed by a long cast. When early trabeculation could be demonstrated roentgenographically as bridging the erased joint surfaces, a molded leather lacer incorporated in a double upright brace was used until firm union could be demonstrated by roentgenograms. Seldom were these patients off crutches postoperatively until at least four to six months had elapsed,—roentgenographic evidence of union rarely being demonstrated before six months. Protection by means of a brace was frequently required for nine to twelve months.

In the twelve compression cases, the compression clamps described by Charnley were used on nine patients and an intramedullary nail was employed in the remaining three,—the compression force in the latter being supplied by the early ambulation of the patient with total weight-bearing. Some question may arise as to whether compression by clamp and compression by weight-bearing of the patient's body are parallel procedures. We believe, however, that use of metallic fixation across a known tuberculous joint is to be avoided, if the same results can be accomplished by other methods. We have used the intramedullary nail only in non-tuberculous patients.

TABLE II

TECHNIQUES FOR ARTHRODESIS OF KNEE JOINT IN NON-COMPRESSION GROUP

Technique	Cases
Crossed Steinmann pins	8
Crossed Steinmann pins with patellar bone graft	3
Crossed Steinmann pins with iliac bone graft	2
Central autogenous tibial bone graft (Hatt)	6
Excision of joint; patella bone graft (Hibbs)	4
Tibial bone graft plus screws	1
Total	24

Postoperative care of those patients in whom the compression clamp was used consisted in suspension in a Thomas splint until the wound had healed (approximately ten to twelve days); incorporation of the extremity in a long cast, including the pins and clamps, with ambulation on crutches; and the removal of the pins after six weeks. At the time of removal of the pins, sufficient clinical union could be demonstrated in all patients, except those with tuberculosis, to allow unrestricted weight-bearing in a plaster cylinder until the consolidation could be verified by roentgenograms. The cylinder was then removed and the patient was allowed to walk without any support. In the tuberculous patients, we were a little hesitant to permit such early weight-bearing.

In those patients in whom an intramedullary nail was used, a pressure dressing with posterior splint was applied until the wound had healed (usually in ten to twelve days). At this time a walking cylinder was applied and immediate ambulation with crutches was allowed; all of these patients were able to walk without any support, other than the plaster, three weeks after the operation. There were no postoperative complications of any type in the compression group. All showed roentgenographic evidence of satisfactory arthrodesis of the joint. The average interval from operation to complete unrestricted weight-bearing, without any means of support, in this group was eighteen weeks; however, when the tuberculous patients, who were denied weight-bearing a little longer, were excluded from this group, the interval was fourteen weeks.

Solid ankylosis was achieved in all but one knee in the entire series. This was in a patient with tuberculous arthritis of the knee, in which there was still clinical motion

FIG. 1-A

Preoperative roentgenograms of a Negro female, aged fifteen years. She had had spine fusion (lumbar) for tuberculosis in 1947. Pain and swelling of right knee occurred in March 1949.

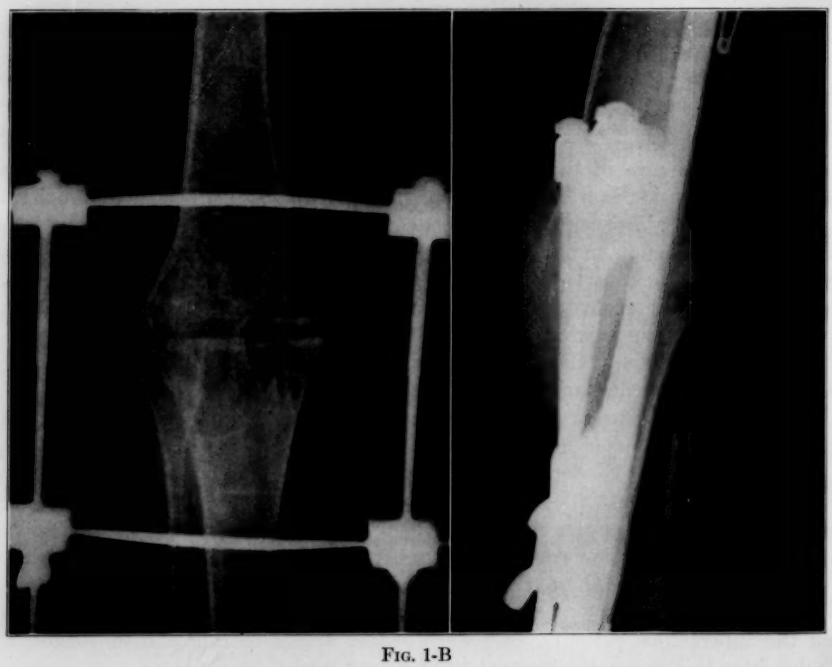

FIG. 1-B

Immediate postoperative roentgenograms, following compression arthrodesis, June 1949. The knee has been fused in extension because of the shortening present. Positive diagnosis of tuberculosis was made from frozen section at the time of operation.

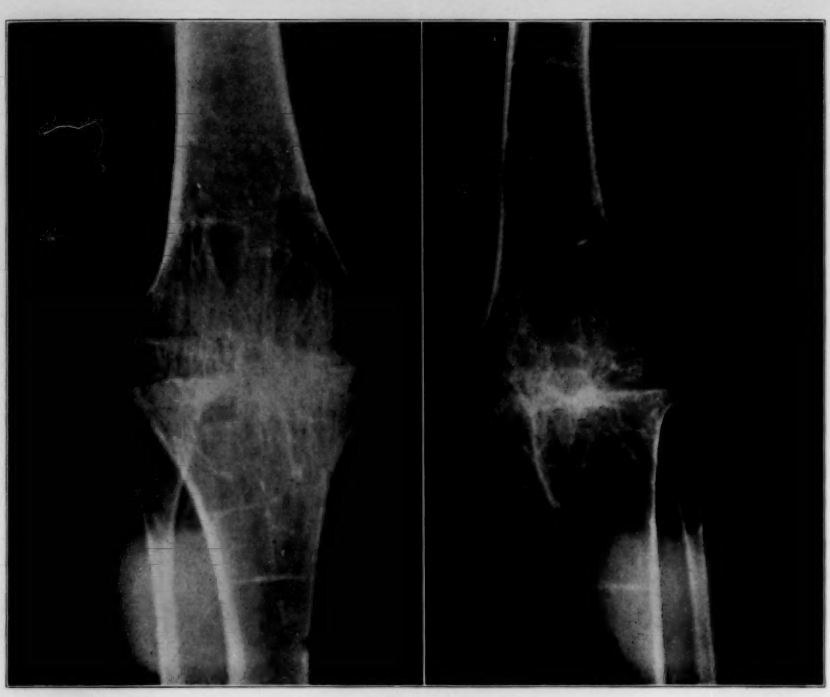

FIG. 1-C

Roentgenograms made thirteen weeks after the operation. Immobilization has been discontinued, and the patient is allowed unrestricted weight-bearing. Streptomycin (42 milligrams) was given post-operatively.

thirty months after operation. The patient is now wearing a brace. In this case, excision of the joint was followed by the implantation of cancellous bone from the ilium and the insertion of crossed Steinmann pins for internal fixation. Both the iliac wound and the knee joint subsequently became infected and drained. Hemolytic streptococci were cultured from both wounds. Antibiotics eventually controlled the drainage, but the result in this case is complete failure of fusion.

Only one other infection was encountered in the entire series. This was originally a compound fracture of the plateau of the tibia with definite sepsis following the original injury. Fusion was performed several years later because of pain and disability. The same technique of erasion of the joint, together with bone-grafting from the ilium and internal fixation with crossed Steinmann pins, was employed. Sequestrectomy was necessary approximately three months after the operation, following which the infection at the operative site subsided. Firm consolidation was evident approximately six months later and no further difficulty has been encountered. It is noteworthy that the only two infections in the entire series were those in which additional bone was employed from a remote site.

REVIEW OF THE LITERATURE

A brief review of the literature reveals that, with all non-compression techniques, the extent of postoperative immobilization is considerable and that the time and certainty of fusion are variable. In 1939, Toumey reported 222 consecutive knee fusions by the Hibbs technique, performed in the New York Orthopaedic Hospital between 1915 and 1936, with an average follow-up of five and one-half years in 199. Fusion occurred in 98

FIG. 1-D

Roentgenograms made five months after the operation, show complete trabeculation of knee joint. There is no evidence of recurrence of disease.

per cent. of these. The average period of immobilization was thirty-two weeks, at which time fusion was considered to be sufficiently solid to permit unprotected weight-bearing. That fifty-nine of the patients were children under ten years of age may have had some bearing on the length of immobilization.

In 1936, Wu and Miltner reported 41 per cent. failures in thirty-nine cases of arthrodesis of the knee for tuberculosis. The fact that all their patients were Chinese in poor general condition and the fact that there were no antibiotics at that time may partially explain such a high percentage of failures.

In 1943, Hatt reported satisfactory fusion following arthrodesis performed by the use of an autogenous central bone peg in twenty-one children, about half of whom had tuberculosis; however, no indications of the duration of immobilization or length of time required for firm fusion are given.

In 1946, Bosworth reported eighteen cases in which arthrodesis was accomplished by use of a three-flanged nail with follow-up in fourteen. Union was secured in thirteen of these. In all except one of these, full weight-bearing was possible in three to six months. This procedure was not used in cases of tuberculosis, osteomyelitis, or active arthritis.

Thus it would seem that, regardless of the technique used, most knees will fuse if immobilized long enough. Because of the variety of pathological conditions present and the individual circumstances existing, we have found it impossible to determine accurately from our own experience the exact economic advantage, from the standpoint of hospital days as well as from the standpoint of early ambulation, which the compression method has over non-compression methods. However, our impression has been, in agreement with that of Charnley and Chapchal, that the method of compression arthrodesis is far superior to any method previously used from the standpoint of technical ease of performance, accuracy of approximation of arthrodesed surfaces, rigidity of fixation, comfort

to the patient in the early postoperative period, early ambulation, and the rapidity and certainty of fusion.

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DISCUSSION

Dr. G. W. N. Eggers, Galveston, Texas: In regard to the work of Dr. Morris and Dr. Mosiman, I am in complete accord with their conclusions. The utilization of the contact-compression factor and compression arthrodesis of the knee has significantly impressed surgeons of its value. The clinical contribution, which shows this method to be superior to previous methods, should stimulate its adoption as a sound, useful, and successful procedure. I am convinced that the method merits acceptance and that it is a preferred procedure in securing arthrodesis of the knee joint.

Dr. David M. Bosworth, New York, N. Y.: It is apparent that the authors have discarded the use of cross pins in knee fusions. With this I am in agreement. Personally, I fear the compounding of bone by pins for several weeks. Numerous complications ensue, including ring sequestrum formation or pinhole infection which may annoy the patient for years or demand local surgical ablation. Since, as they say, "regardless of the technique, most knees will fuse if immobilized long enough", one should not gamble on the complications of external fixation to gain two to six weeks' time. This is especially true since, with either a simple Hibbs fusion (where stability permits) or fusion plus an internal metal guide, ambulation with actual weight-bearing in a cylinder cast is permissible on crutches within two to three weeks. One need not use spica casts. Continued coaptation or impaction of a loose knee arthrodesis by weight-bearing not only seems as efficient as external-pin fixation and compression, but is also without the dangers.

The tuberculous knee is a separate problem. How distinct it is, few realize. Internal or external fixation may implant the tubercle bacillus beyond its original confines or unwittingly transverse areas of caseation not visualized from roentgenograms or seen at operation. Simplicity of fusion technique is here imperative. Hemifusion in such joints, away from draining sinus, with completion of the operation by hemifusion on the opposite side at a later date may be necessary.

PIGMENTED VILLONODULAR SYNOVITIS OF ILIOPECTINEAL BURSA

A Case Report *

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It is the purpose of this article to call attention again to the fact that the presence of a mass in the subinguinal or femoral area requires consideration of the possibility of a lesion affecting the iliopectineal bursa, to state that this bursa may undergo pathological change (designated as pigmented villonodular synovitis), and to emphasize that this condition is not well understood, particularly as regards its origin and prognosis. Finder, in discussing the syndrome of iliopectineal bursitis, mentions that in one case "Competent internists, surgeons and orthopedists examined the mass and made several diagnoses, but iliopectineal bursitis was not mentioned even indirectly".

It is, of course, well known that there are many bursae about the region of the hip joint. Of these the iliopectineal is the largest and most constant, and it may or may not connect directly with the synovial-lined joint cavity. Connections, when they exist, may be congenital, or may be the result of friction or of trauma. The iliopectineal bursa may be small, overlying only the area of the joint, or it may extend either cephalically or distally, or both, being limited only by the extent of the sheaths of the iliopsoas or pectineal muscles.

It has been pointed out by Jaffe, Lichtenstein, and Sutro, with whom the term "pigmented villonodular synovitis" originated, that a bursa may be the site of a pigmented villonodular lesion similar to those seen in articular synovial membranes. They state, further, that this is not a very familiar fact, possibly because of the rarity of this type of lesion in bursae. Certainly most of the reported lesions of pigmented villonodular synovitis have been in and about the knee joint and the smaller joints located in the distal portions of the extremities. In many cases, the lesions have affected only the tendons and more particularly the tendon sheaths of the extremities. The lesions of the tendon sheaths have been designated as pigmented villonodular tenosynovitis and have been described along with giant-cell tumors and xanthomata of the tendon sheaths. Few cases have been reported in which the lesion was located in the larger bursae of the hip or shoulder.

CASE REPORT

A twenty-eight-year-old white enlisted man of the Army was admitted to the Hospital on July 20, 1950, complaining of pain and swelling in the right groin which was becoming progressively worse. He had first noted pain in the right hip while standing guard duty the previous night. Walking increased the pain which migrated to the groin where it became localized. About twelve hours prior to admission, a mass appeared. Full extension or flexion of the hip joint aggravated his symptoms, but he had had no nausea or vomiting, nor had he had a bowel movement in the past thirty-six hours.

Past history contributed a vague account of transitory, mild discomfort in the hip after prolonged walking or standing.

Physical examination revealed an acutely ill, dehydrated patient with a temperature of 100 degrees Fahrenheit. Except for the right inguinal region the examination was non-contributory. The abdomen was soft and without evidence of distention. On the anterior medial aspect of the right thigh, lateral to Poupart's ligament, was a firm mass measuring eight by three centimeters, lateral and anterior to the femoral vessels. The white-blood-cell count on admission was 16,000 with a normal hemogram. Urinalysis was normal. Roentgenograms of the hip and lower abdomen were made, which were negative. The diagnosis of strangulated femoral hernia could not be ruled out, and the patient was subjected to immediate exploration.

* The statements and conclusions published by the authors are a result of their own study and are not to be construed as reflecting the policy of the United States Navy or a part thereof.

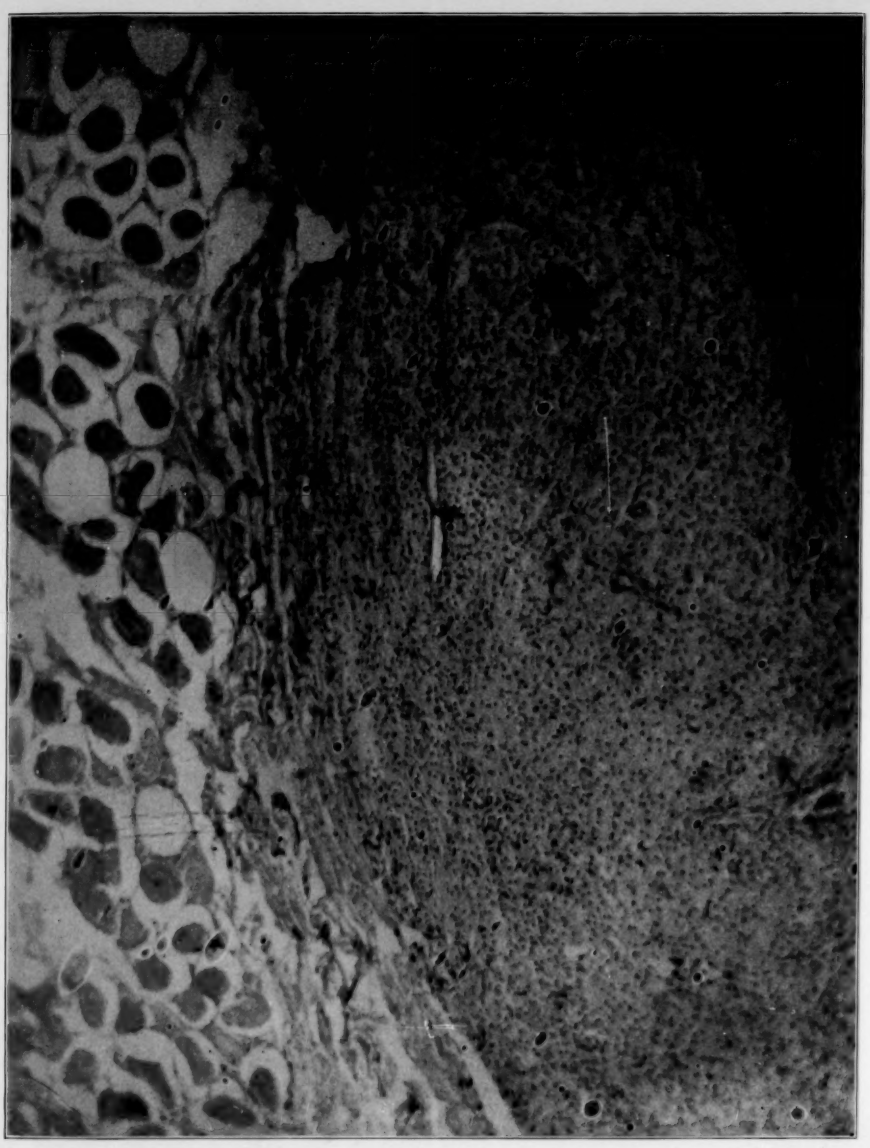

FIG. 1

This section (× 7) represents the bursal wall with regional voluntary muscle. Large cells with foamy cytoplasm and small round nuclei are present. In some areas, Touton giant cells may be seen. There is moderate vascularity, and a collection of granular hemosiderin pigment may be seen.

A five-inch curved incision was made over the upper medial edge of the sartorius, and a cystic mass was encountered, connecting proximally with a continuation dorsal and slightly lateral to the femoral and lateral iliac vessels. An inguinal incision was then made, and the mass was followed extraperitoneally inside the iliopsoas fascia to the origin of the iliacus on the lateral wall of the pelvis. Distally the attachments had become fused with the insertion of the iliopsoas at the lesser trochanter. The cyst was filled with a thick yellow fluid, and the thickened fascia and tendon appeared yellowish and contained soft disintegrated granulomatous areas. Because of the wide attachment to bone, complete excision was not possible.

Histological examination showed an inner lining of synovial membrane with epithelium-like lining cells and numerous villous-like processes. Within the villi were numerous dilated blood vessels, a scanty fibrous

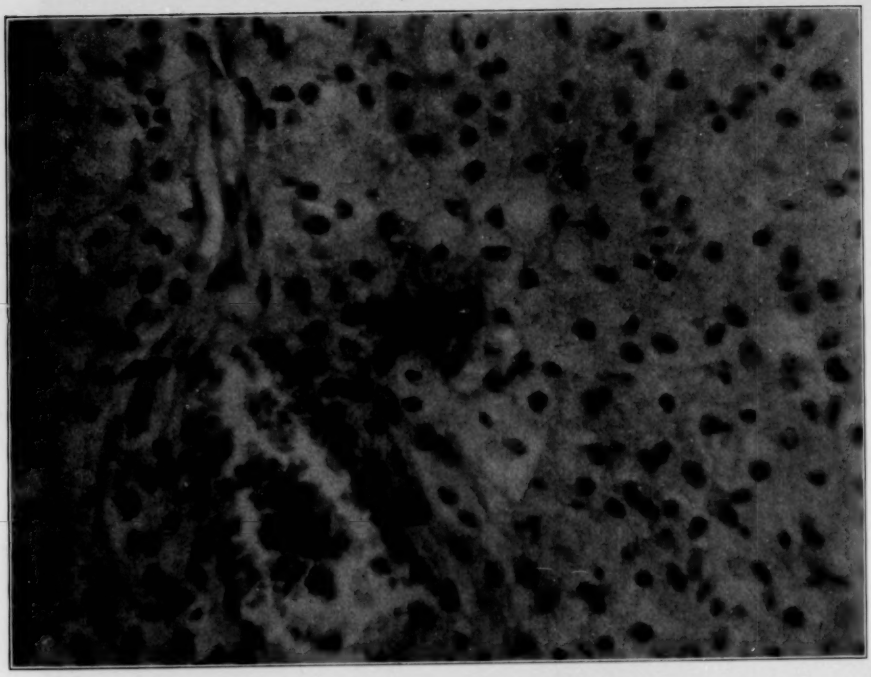

FIG. 3

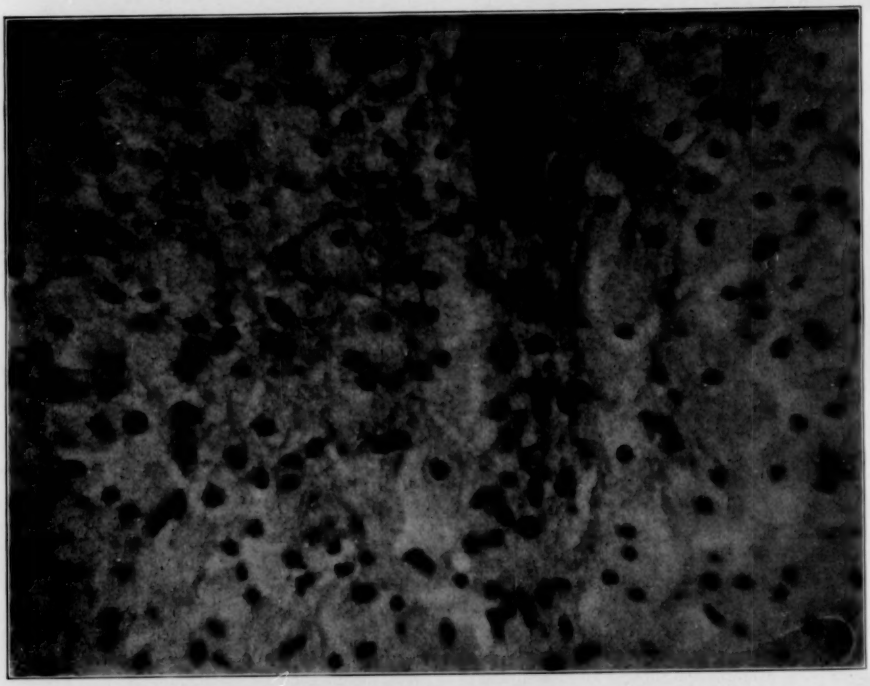

FIG. 2

These sections (× 38), higher magnification than Fig. 1, show the foam cells and vascular spaces.

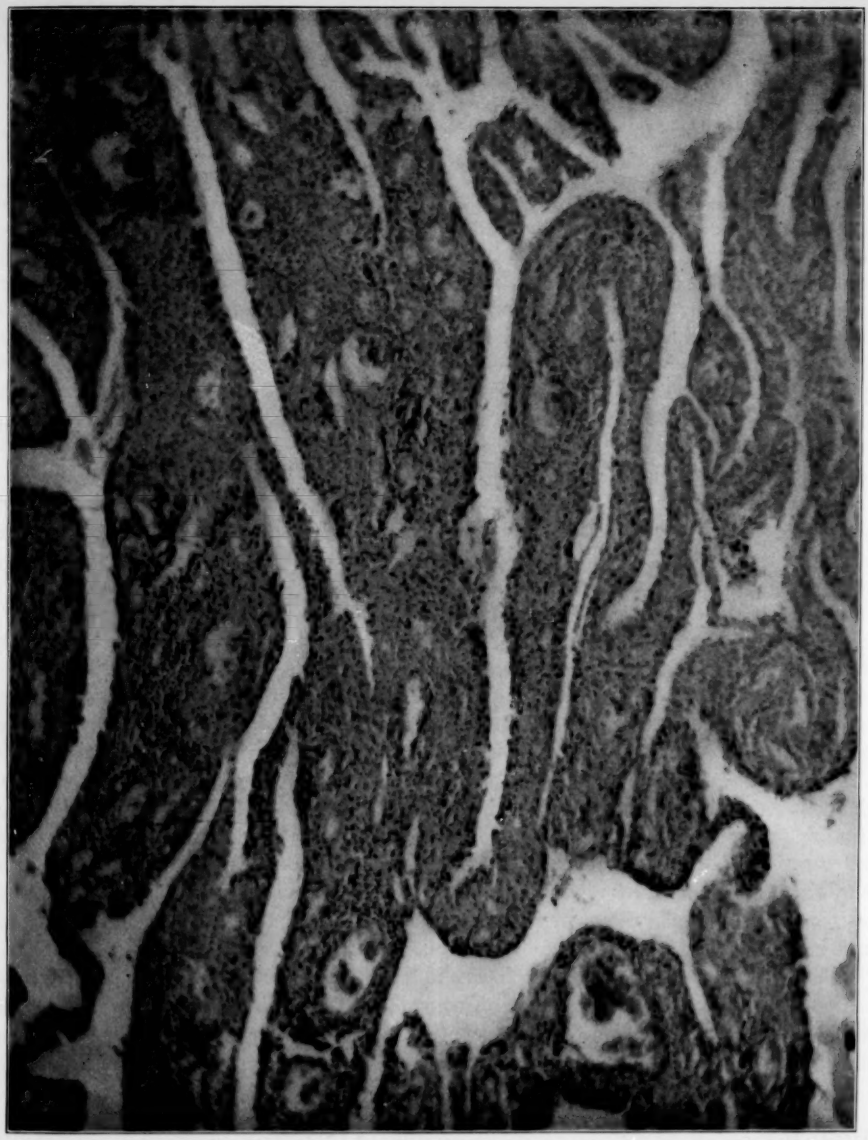

FIG. 4

Photomicrograph (× 7) showing the villous pattern which arises from the synovial surface. The villi are lined by flattened epithelial-like cells. The core is moderately vascular with focal collections of polymorphonuclear leukocytes, foam cells, and hemosiderin pigment.

stroma, and many masses of granular hemosiderin pigment. Some of the villi contained foam cells. The lining synovial cells in places were three or four layers thick, and all had small, benign-appearing nuclei. In the wall of the cyst and corresponding to the nodular yellow areas in the gross specimen were large collections of foamy histiocytes and giant cells of the Touton type. There were also present focal collections of granular hemosiderin pigment in the stroma.

The diagnosis was pigmented villonodular synovitis of benign synovioma as made by R. H. Fuller, M.D. The slides were reviewed and diagnosis was concurred in by G. A. Bennett, M.D.

The patient's postoperative course was good and he was ambulatory on the third day after the operation. He made an uneventful recovery. When he was seen ten weeks following surgery, he was entirely without

These sections (× 38), higher magnification than Fig. 1, show the foam cells and vascular spaces.

symptoms, and there was no evidence of any recurrence. He was seen again on November 17, 1950, five months after the operation. There were no signs of recurrence, but slight tenderness was elicited on deep pressure over the iliopectineal area. Roentgenographic examination was non-contributory for evidence of bone changes in the pelvis and the femora.

This patient was again examined on June 20, 1951. No evidence of local recurrence was found. Roentgenographic examination of the chest and bones showed no evidence of metastatic involvement.

DISCUSSION

Pigmented villonodular synovitis is a diagnosis largely provisional and descriptive in nature. It does not definitely classify the lesion as to its origin (inflammatory or neoplastic) or its nature and potentialities (benign or malignant). Since Smith, in 1927, traced the origin of synoviomata, some work has been done in an effort to clarify the pathology of these and related lesions. Haagensen and Stout have emphasized that in giant-cell tumors and synovial hyperplasia, the lining cells of the synovial membrane are especially affected, whereas in synovial sarcoma there are two tissue elements sharply contrasted, one reproducing a caricature of synovial structure and the other resembling fibrosarcoma, but that the two are inextricably mingled. Murray, Stout, and Pogogeff made interesting studies on synovial sarcoma and normal synovial tissue cultivated *in vitro*. They concluded that the normal synovial cell appears to be a specific cell type, distinct from other epithelium and from the fibroblast. The synovial sarcoma appeared to be a distinct type of neoplasm exhibiting certain similarities to the mesotheliomata. Bennett, who has contributed extensively to the knowledge of reactive and neoplastic changes in synovial tissues, places the lesion of pigmented villous synovitis and pigmented villonodular synovitis in a position between those clearly inflammatory in nature and those definitely neoplastic. He notes that many of the histological characteristics of pigmented villonodular synovitis are similar to those encountered in the recognized neoplasms of synovial origin. Nearly all lesions designated as pigmented villonodular synovitis have been intimately related to the synovial membranes about the articular surfaces, especially of the knee and the smaller joints in the more distal portions of the extremities. When a larger bursa, such as those about the hip or shoulder joint, is affected, it is difficult to prove or disprove existing or prior connection with the synovial membrane of the joint. A previously existing communication may have become closed by the disease process, or the synovial membrane of the joint may have been inadvertently opened during the dissection of an adherent bursa containing pigmented villonodular material. The exact origin of a lesion may not then be possible to determine; however, the relationship of synovial membrane and tendon-sheath tissue is so close that it is not surprising to find similarities between lesions affecting them.

At present this lesion must be placed in a somewhat nebulous realm occupying a position between that of the benign neoplasms designated as giant-cell tumors of tendon sheaths, and that of the frankly malignant lesions, called synoviomata, arising from the cells lining synovial cavities.

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ROTATION OF THE FOREARM*

An Experimental Study of Pronation and Supination

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It is generally taught in medical schools that the motion of pronation and supination of the forearm occurs about an axis which passes through the capitulum of the humerus and the distal end of the ulna, with the radius revolving about the ulna while the latter remains stationary. However, when motions of the forearm are studied in living subjects, it appears that the distal end of the ulna moves in a lateral plane, and in a direction opposite to that taken by the radius. In other words, it appears that the ulna is abducted during pronation and adducted during supination. The purpose of this study was to determine whether this motion of the ulna is real or apparent.

METHOD

For purposes of the experiment it was necessary to eliminate motion of the humerus. Accordingly, after several trials, an apparatus was designed (Fig. 1) by which two pins measuring five thirty-seconds of an inch could be inserted under local anaesthesia into the epicondyles of the humerus and held rigidly with clamps. The apparatus was mounted on a wooden frame which served as a holder for a cassette, fourteen by seven inches. Incorporated in the frame was a Steinmann pin marker, so that any motion of the film between exposures would be apparent. The pins were inserted into the cortex of the epicondyles of the humerus under sterile precautions and clamped to the frame. A roentgenogram was made with the forearm in maximum pronation, and a second exposure was made on the same film with the arm in maximum supination. Two axes of rotation were used in taking these films, the index finger in the first and the fifth finger in the second. In order to steady the arm during rotation about these axes, a wire Chinese finger basket and rubber-band traction were used. Double-exposure photographs were also made with the arm immobilized in the apparatus. The procedure was carried out on two subjects (the authors).

The second method of visualizing the motion occurring in the forearm during pronation and supination was by means of cinefluorography; this part of the experiment was carried out on five medical students.

The third method used in the study was a combination of motion-picture photography and electromyography. Bipolar needles were inserted into the anconaeus, flexor carpi ulnaris, and extensor carpi ulnaris. A Grass amplifier was used to record the action potential of muscles during the motion of the forearm. In order to correlate the position of the forearm with the muscle contractions, motion pictures of the forearm and the electromyographic recording were made simultaneously.

RESULTS

It was found that, with the epicondyles of the humerus fixed by means of pins, the axis around which pronation and supination took place could be varied. When this motion occurred around an axis passing through the ulna and the fifth finger, the palm of the hand was transposed, as shown in the double-exposure photograph (Fig. 2). Double-exposure roentgenograms revealed that the ulna remained relatively stationary (Fig. 3).

* Presented at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 26, 1951.

However, it should be noted that it was difficult to keep the ulna stationary voluntarily during pronation and supination, even with the humerus fixed and the fifth finger in traction. Pronation and supination could also take place around an axis passing through the index finger. In this case the palm of the hand was not transposed but remained in alignment with the axis of rotation of the forearm (Fig. 4). During pronation around this axis the ulna was abducted and during supination it was adducted, the actual arc of motion from full supination to pronation being 8 to 9 degrees (Fig. 5). Cinefluorography confirmed these findings.

Active abduction of the ulna during pronation theoretically could be produced by any muscle passing in an oblique direction from the lateral aspect of the humerus to the ulna. There are two such muscles, the extensor carpi ulnaris and the anconaeus. Electromyograms of the former showed little or no action, but a significant action potential could be obtained from the anconaeus from the onset of pronation to the fully completed movement. It is of interest to note in passing that the potential obtained from the anconaeus during extension of the elbow—the action classically ascribed to this muscle—was insignificant.

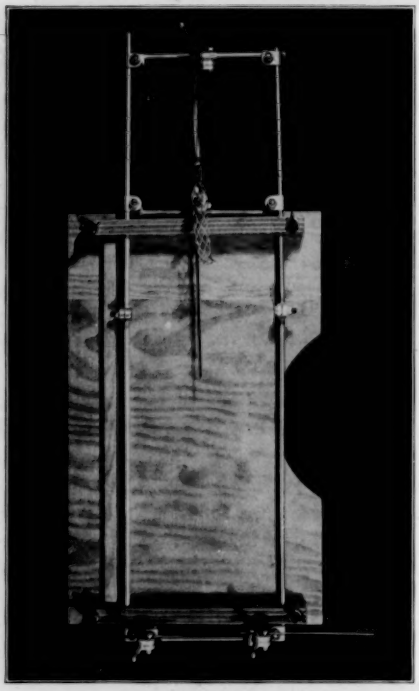

FIG. 1

Apparatus for immobilizing the humerus. At the lower border of the picture are shown the pins inserted into the epicondyles of the humerus. Also illustrated is the wooden frame, designed to hold a cassette measuring fourteen by seven inches, the Steinmann-pin marker, and the wire Chinese finger basket used as an axial guide during pronation and supination of the forearm.

DISCUSSION

The classical anatomical view that the ulna remains stationary during pronation and supination was attacked by Vicq d'Azyr, Winslow, Lecomte, and Duchenne between 1860 and 1875. At that time, the views of these authors attracted more ridicule than serious attention. Wilhelm Braune and Alfred Flügel in 1882, following investigations on fourteen cadavera, stated flatly that Lecomte's opinion about pronation and supination was erroneous, and that the radius alone moves about the ulna. The question was reopened in 1884 by Jacob Heiberg, Professor of Anatomy at the University of Christiana, and in the same year by Thomas Dwight, Professor of Anatomy at Harvard. Heiberg, using a cadaver, fastened the humerus to a board, and after disarticulating the wrist, affixed paint brushes to the distal ends of the radius and ulna. With the wrist encompassed in a ring according to the method of Lecomte, pronation and supination caused both brushes to describe arcs of circumduction. Dwight confirmed these findings. In 1901 Richard Anderson, Professor of Natural History, Mineralogy, and Geology at Queen's College, Galway, entered the argument and showed by means of a mirror fixed over the styloid process of the ulna, as well as over the olecranon process, that the movement of the ulna could be magnified by deflecting a beam of light.

Dwight quotes a Mr. Wagstaffe who, in a review of Heiberg's book, wrote wistfully in the London Medical Record for July 1884 that he hoped "to see the results of Professor Heiberg's observations incorporated in our anatomical and surgical text-books". Although

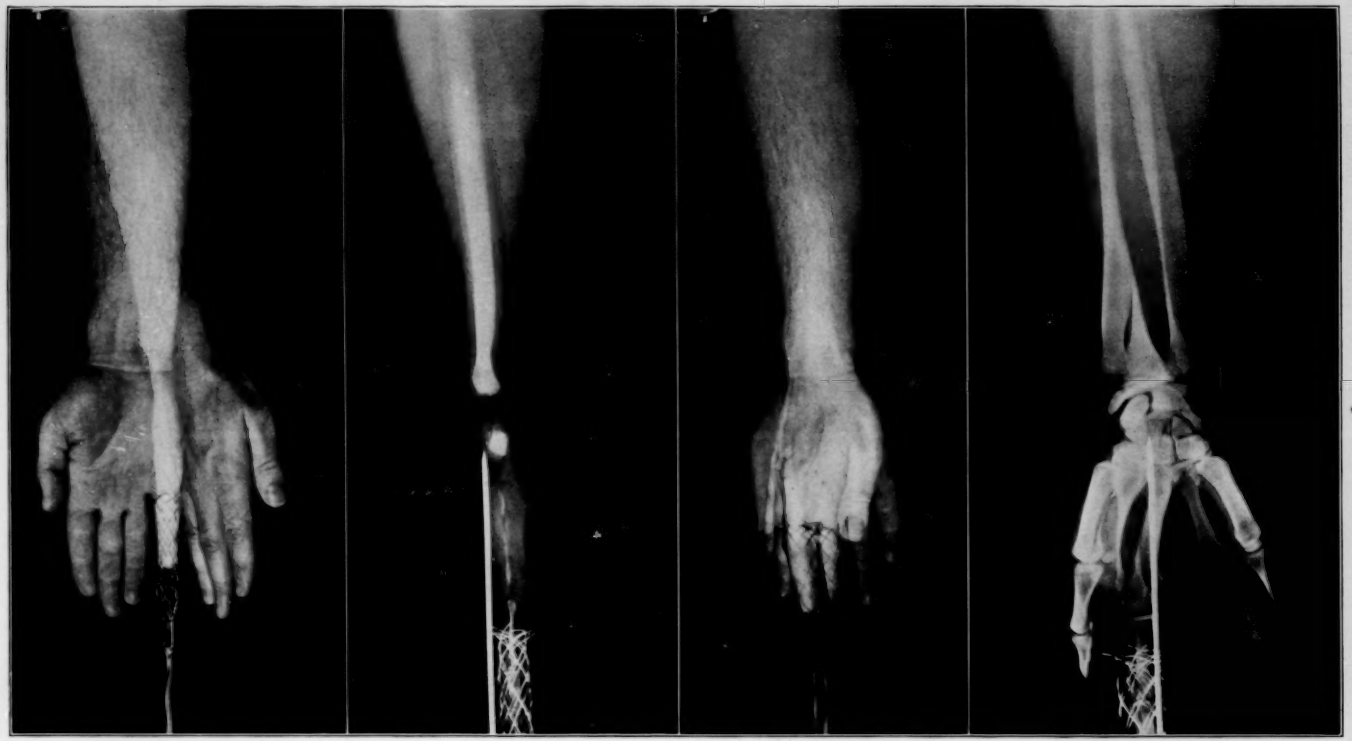

FIG. 2 FIG. 3 FIG. 4 FIG. 5

Fig. 2: Double-exposure photograph of hand and forearm during pronation and supination around an axis passing through the fifth finger, showing transposition of hand. The humerus is immobilized.

Fig. 3: Double-exposure roentgenogram corresponding to Fig. 2, showing relative immobility of ulna.

Fig. 4: Double-exposure photograph of hand and forearm during pronation and supination around an axis passing through the index finger, with the humerus immobilized, showing hand remaining in alignment with forearm.

Fig. 5: Double-exposure roentgenogram corresponding to Fig. 4, showing displacement of ulna.

motion of the ulna is mentioned by both Gray and Cunningham, such standard texts as those by Grant, Callander, and Jones, as well as a recent article on pronation and supination by Patrick, are evidence that it has not yet been uniformly accepted.

From the results of the present experiment it is apparent that, although limited pronation and supination can occur with the ulna remaining stationary, under ordinary circumstances the distal end of the ulna moves laterally as the radius travels medially during pronation, and that during supination the ulna moves in the opposite direction. The point is not merely an academic one. Duchenne describes a case with limitation of pronation and supination following ankylosis of the humero-ulnar articulation. When the patient wanted to use his hand in pronation and supination he turned the humerus, with resultant loss of strength and awkwardness of motion. One of the present authors has observed two patients with fractures of the distal end of the humerus involving the trochlea, which resulted in loss of motion of the ulna in pronation and supination. Both patients complained of awkwardness and weakness in using screw drivers, pliers, and similar tools.

SUMMARY

Photographic, roentgenographic, cinefluorographic, and electromyographic studies of pronation and supination of the forearm reveal:

1. That under ordinary circumstances the ulna is abducted during pronation and adducted during supination;

2. That contraction of the anconaeus can produce abduction of the ulna.

NOTE: The cinefluorographic studies were made with the generous cooperation of Dr. Rushmer of the Department of Physiology.

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EPIPHYSEAL CHONDROBLASTOMA OF BONE

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This paper deals with a tumor of the chondroblastic series which has been recognized as an entity only recently. The clinical and histopathological characteristics of this tumor are well defined. Its correct classification is of considerable practical importance in that it helps toward correct prognosis, adequate treatment and, above all, the obviating of unnecessary mutilating operations.

Codman and Ewing called this tumor a chondromatous or calcifying variant of giant-cell tumor. Geschickter and Copeland [6] first believed it to be a chondroblastic sarcoma; they later modified this classification and considered it a benign or malignant chondroblastoma[8]. Jaffe and Lichtenstein called it a benign chondroblastoma. Interest in these studies led to a review of our own clinical and pathological material and to the discovery of eight cases which may come within this classification.

In a review of the literature, priority in the segregation of this tumor group is attributed to Ewing who in 1928 described it as a "calcifying giant-cell tumor". However, Kolodny, one year before, had described a "variant of giant-cell tumor" associated with "absorption of aberrant islands of cartilage" which corresponded to the tumor in question.

Codman described an "epiphyseal chondromatous giant-cell tumor of the upper end of the humerus", citing nine instances from the Registry of Bone Tumors, all of which occurred in patients aged twelve to twenty-five. He emphasized the benign nature of the tumor, and also the difficulties in histological diagnosis. On the other hand, Geschickter and Copeland, in the first edition of their book, emphasized the malignant character of the tumor, while in more recent publications they state that some of the lesions are benign while others are malignant. The papers of Phemister, King, Ardao, Hammarström, Coley and Santoro, and Lichtenstein and Kaplan contributed additional material. Other cases, usually reported as cures of chondrosarcoma by conservative therapy, probably belong to this group of lesions.

Jaffe and Lichtenstein were the first to suggest that these tumors were chondroblastic

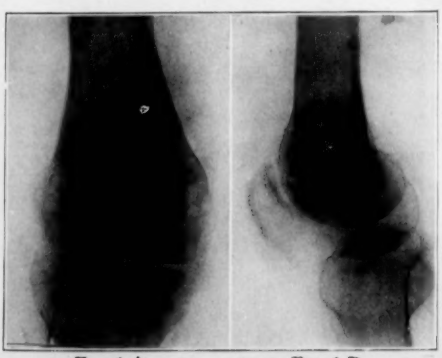

FIG. 1-A

FIG. 1-B

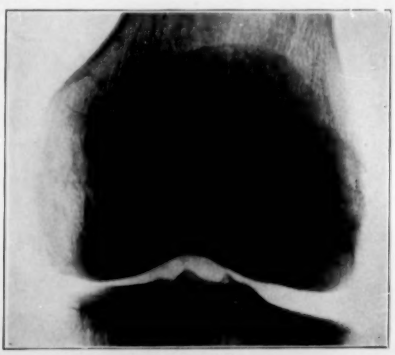

FIG. 1-C

Figs. 1-A and 1-B: Case 1. J. M., male, eighteen years old. Admitted April 22, 1940, with pain of three years' duration. Roentgenograms showed an osteolytic lesion in the lateral femoral condyle. Biopsy made in another hospital led to a diagnosis of sarcoma and amputation was proposed. After infection of the biopsy wound, aspiration biopsy revealed a benign tumor. Roentgen therapy was instituted.
Fig. 1-C: Result of roentgen therapy after eight years: full recovery.

in origin but were not sarcomata or variants of giant-cell tumors. They emphasized the origin in the epiphysis of long bones but without the predilection for the proximal end of the humerus as affirmed by Ewing and Codman. They also showed that the treatment of choice was curettement with or without roentgen irradiation.

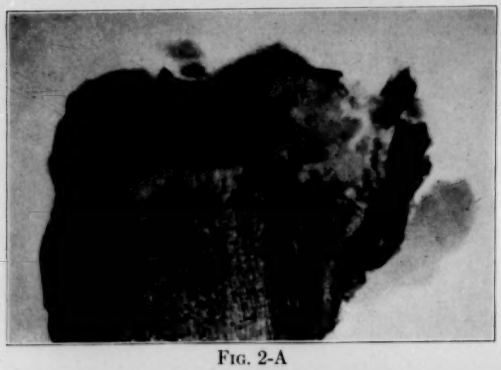

FIG. 2-A

Case 2. C. M., female, sixteen years old. Admitted April 12, 1943, with pain of eight months' duration. Roentgenogram of resected specimen shows osteolytic lesion of proximal tibial epiphysis and joint involvement.

CLINICAL CHARACTERISTICS

Epiphyseal chondroblastomata originate during the adolescent years, or just after epiphyseal closure has

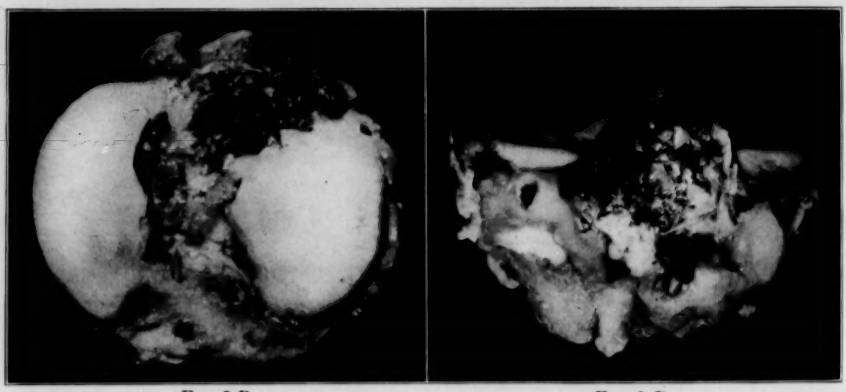

FIG. 2-B FIG. 2-C

Photograph of resected specimen. The principal tumor mass is located in the posterior portion of the proximal tibial epiphysis and invades the joint; the mass is irregular and reddish pink.

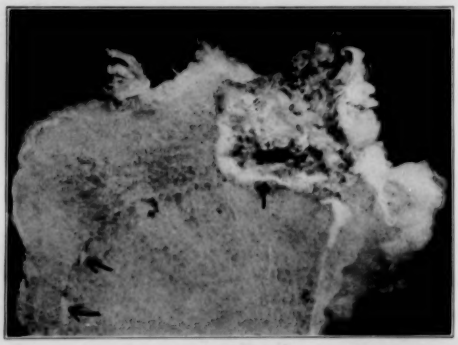

FIG. 2-D

Fig. 2-D: Sagittal section showing the relation of the tumor to the epiphyseal plate. The arrows indicate the remaining epiphyseal cartilage.

Fig. 2-E: End result seven years after resection and implantation of grafts.

FIG. 2-E

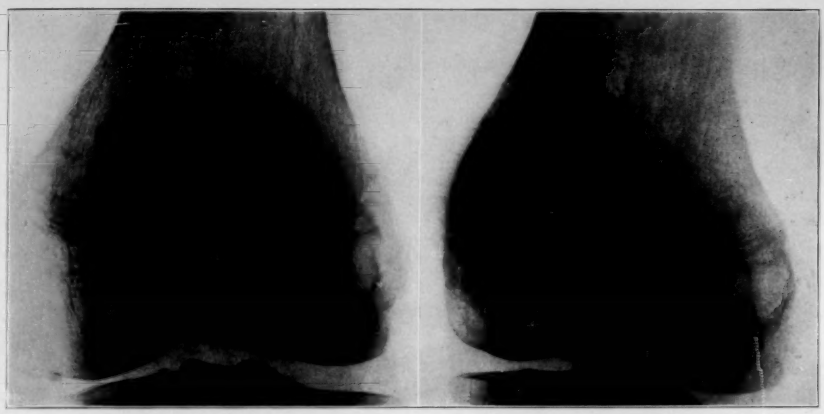

FIG. 3-A FIG. 3-B

Case 3. J. D. M., male, seventeen years old. Admitted May 13, 1944, with pain in the lateral femoral condyle since August 1943. There was an osteolytic lesion extending through the cortex. Six years later, there was full recovery after treatment by curettement and bone grafts.

been completed. Since they have their origin in the epiphyseal cartilage, they do not occur after growth has ceased and the epiphyseal cartilage has disappeared.

Our patients ranged in age from thirteen to eighteen; Jaffe and Lichtenstein's patients belonged to approximately the same age group. The location of the tumor was in relation to the epiphyseal cartilage. In the reports cited, the most frequent sites were the distal epiphysis of the femur and the proximal epiphyses of the tibia and humerus. Our eight cases were: in the distal epiphysis of the femur, two; proximal epiphysis of the humerus, two; head of femur, two; proximal epiphysis of the tibia, one; and talus, one.

The clinical symptoms of the tumors were not characteristic. Pain and swelling were the most frequent complaints. The pain was usually moderate but, if the joint was involved, arthritic pain was superimposed. Lymph-gland enlargement was present in three cases. Pathological fractures were uncommon (there are only three recorded cases).General symptoms were absent. The usual laboratory tests were not helpful in diagnosis; in some cases the sedimentation rate was slightly elevated.

ROENTGENOGRAPHIC FINDINGS

The characteristic lesion was a round or oval well-defined area of destruction in the cancellous bone. Some reaction to this destruction often was evident, but usually the

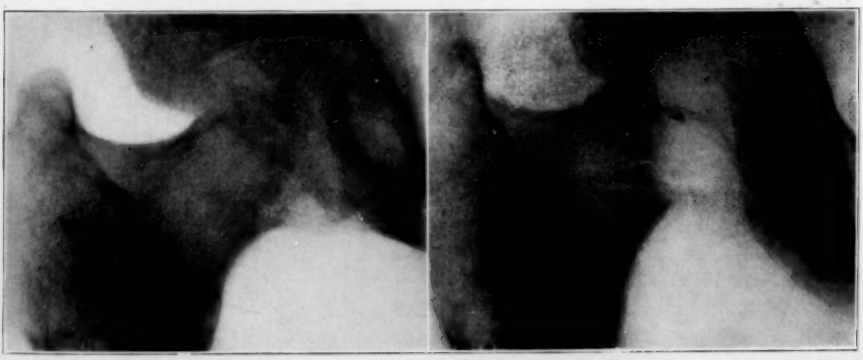

FIG. 4-A FIG. 4-B

Case 4. A. G., female, eighteen years old. Admitted November 14, 1944, with pain in the hip and knee since August 1943. A previous diagnosis, made in another hospital, had been tuberculosis of the hip joint.

FIG. 4-C FIG. 4-D FIG. 4-E

Fig. 4-C: Showing destruction of the acetabulum and the femoral head and neck, with subluxation.
Fig. 4-D: After roentgen therapy there was evident calcification of the tumor.
Fig. 4-E: A subtrochanteric osteotomy was performed. The period of observation in this case was six years. At the end of this time no new symptoms had appeared and the patient's general condition was good.

FIG. 5-A FIG. 5-B FIG. 5-C

Case 5. M. N. J., female, thirteen years old. Admitted December 20, 1946, with pain in the proximal end of the humerus of two years' duration.

Figs. 5-A and 5-B: Showing a roundish, well-defined area of destruction with sclerotic border.

Fig. 5-C: Follow-up roentgenogram after five years. Treatment by curettement and bone graft yielded an excellent result, and there were no symptoms.

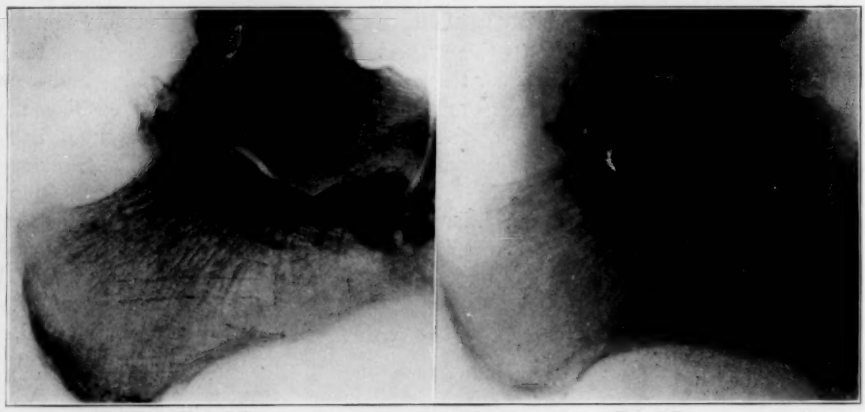

FIG. 6-A FIG. 6-B

Case 6. B. F., male, eighteen years old. Admitted August 3, 1947, with pain in the ankle since May 1947. Destruction of the posterior part of the talus and invasion of the joint are evident.

Treatment was by curettement. The patient was asymptomatic two and a half years after treatment.

border of the lesion was irregular, fuzzy, or vague. Codman commented on the mottled appearance of the lesion and described it as resembling flakes of cotton. The characteristic trabecular appearance and cortical expansion of giant-cell tumors were absent.

The position of the lesion in relation to the epiphyseal plate was variable; in six of our cases the tumor was predominantly on the epiphyseal side, but one tumor invaded both the joint and the metaphysis (Case 4). In one case the tumor was entirely on the metaphyseal face of the epiphyseal cartilage (Case 5). The lesion of the talus (Case 6) was mainly central but involved the posterosuperior border.

Subperiosteal bone production occurred in only one of our cases (Case 7). This is contrary to the observations of Geschickter and Copeland [8], who found that the periosteal reaction usually extended from metaphysis to diaphysis, providing a characteristic by which this condition may be differentiated from Ewing's tumor.

Serial roentgenograms sometimes revealed growth toward the joint, and transarticular spread was observed in two of our cases, one involving the femoral capital epiphysis and the other the proximal epiphysis of the tibia.

PATHOLOGICAL FINDINGS

In three of our cases the material for study was obtained by means of biopsy; in four cases by curettement of the whole lesion, and in one by resection.

Macroscopic Findings

Grossly the resected lesion from the tibia (Figs. 2-A, 2-B, 2-C, and 2-D) was irregularly rounded and measured about three centimeters in diameter. It was located posteriorly and was adjacent to the epiphyseal plate, from which it appeared to have originated. There was no clear demarcation from the adjoining spongy bone. Penetration of the joint by a lobular hyperaemic mass was observed posterior to the tibial spine. The periosteum of the posterior proximal portion of the tibia was thickened and hyperaemic, but no new bone was evident subperiosteally.

The tumor tissue in the resected specimen, as well as in the material from biopsies and curettings, was grayish-pink. Yellowish zones of calcification, bluish-gray nodules (cartilage), and hemorrhagic areas were also present. The texture was usually rubbery, but areas of firmness and areas of friability also were present, corresponding respectively to cartilaginous, calcific, and hemorrhagic foci.

Microscopic Findings

Microscopically, the predominant tissue usually was compact and cellular and was similar to that of a giant-cell tumor. In some specimens, however, the cartilaginous tissue comprised the greater part of the tumor tissue. The cartilage was present in lobules and showed variable calcification. Between the lobules, cells originating in the cartilage and exhibiting a polymorphic character occurred. These cells suggested that the tumor had a sarcomatous character and, indeed, three of our cases had been diagnosed as sarcomata before the paper by Jaffe and Lichtenstein came to our notice. Where the cartilaginous portion of the tumor was meager, the similarity of most of the tissue to that of giant-cell tumors became evident, although giant cells usually were not numerous.

The basic cell of the tumor was round or polyhedral and was of medium size. Its nucleus was large and often polymorphic (round, oval, or reniform) with one or two nucleoli. The cytoplasm was acidophilic, and the cell borders were sharply demarcated, even where compact sheets of cells occurred, and little or no interstitial substance was found with the usual stains. The material for Rio Hortega's silver stains was formalin-fixed and cut into frozen sections without decalcification. This method stains the calcium deposits as well as the reticulin fibers and is superior, in our opinion, to von Kossa's stain for localization of calcium. The Rio Hortega stain showed that these cells were surrounded by reticulin fibers individ-

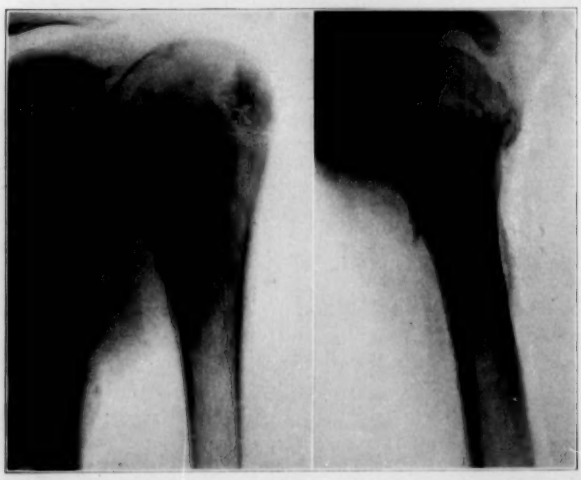

FIG. 7-A FIG. 7-B

Case 7. H. J. S., male, fourteen years old. Admitted July 4, 1944, with pain in the shoulder region since February 1944.

Roentgenograms revealed an osteolytic lesion with subperiosteal bone formation. Biopsy showed the features typical of epiphyseal chondroblastoma. This patient was not treated and was lost to follow-up examination.

FIG. 8-A

FIG. 8-B

Case 8: D. D., male, seventeen years old. Admitted December 12, 1949, with pain in the hip joint since December 1948.

Fig. 8-A: Roentgenogram made December 1948, showing osteolytic lesion in the proximal portion of the femoral head. A diagnosis of tuberculosis was made at this time.

Fig. 8-B: Roentgenogram made at the time of admission to the Hospital. Involvement of the joint is evident. Aspiration biopsy led to a diagnosis of epiphyseal chondroblastoma.

Fig. 8-C: Roentgenogram made in January 1951, showing result of treatment by curettement and bone graft.

FIG. 8-C

ually and in small groups (Figs. 12-C and 12-D) and, in rare instances, reticulin fibers also surrounded the large cellular masses. The reticulin fibers were most numerous at the zones of cell proliferation in the tumor, and rare where the chondroblastic differentiation into cartilage was occurring. With the Rio Hortega technique for reticuloendothelial elements it could be shown that a basic tumor cell was of a reticulohistiocytic nature, with its characteristic ramefied or amoeboid aspect, forming small or large groups (Figs. 12-A and 12-B). The tumor cells occasionally had two or three nuclei and thus displayed the intermediary stages of giant-cell formation. We do not believe that the origin of giant cells was in fusion of mononuclear cells, as Jaffe and Lichtenstein suggested, but rather that it occurred mainly through the amitotic division of the stromal cells, as we have been able to show in the tissue culture of a giant-cell tumor [16]. Giant cells in this tumor usually were small or of medium size and contained about fifteen nuclei. They were present, not only at the border of hemorrhages, but at the region of chondroblastic differentiation, and thus within the tumor-cell mass. The chondroblastic tissue frequently showed irregular foci of calcification. The calcium granules were always extracellular, and it could not be proved that intense calcification produces necrosis of the tissue followed by slow replacement of the dense hyalinized collagenous tissue and hyaline cartilage. Areas of formation of hyaline cartilage occurred without previous calcium deposits, as did areas of necrosis. The necrotic areas tended to become calcified in time.

The tumor showed many blood vessels and spaces, some of which lacked endothelial cells and were lined by tumor cells. Occasionally the vessel walls were thickened. In the bone adjacent to the tumor there could be seen fibrous marrow, osteoid, and new-bone trabeculae, and these often subdivided the tumor into lobules. In the resected specimen, perforation of the articular cartilage was seen. In none of the specimens were atypical mitoses found. A few normal mitotic figures were seen in the tumor elements.

FIG. 9-A FIG. 9-B FIG. 9-C

Photomicrographs showing typical histological features of the tumor, and showing cartilage, chondroblastic cells, giant cells, and variability within the tumor

FIG. 10-A FIG. 10-B FIG. 10-C

High-power photomicrograph, illustrating the cytological features; scattering of multinuclear giant cells of medium size is seen in stroma rich in cells of roundish, ovoid, or polyhedral shape, with ovoid or reniform nuclei of reticulohistiocytic aspect and in chondroblastic evolution.

TREATMENT AND PROGNOSIS

The treatment indicated was conservative. In our cases, curettement alone was used in one case (Case 6); curettement with insertion of bone chips in two cases (Cases 3 and 8);

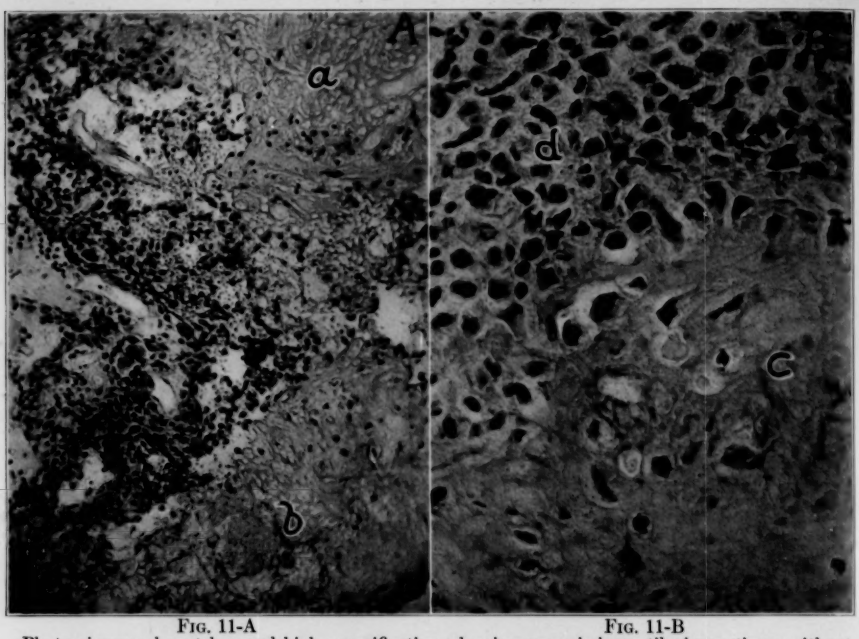

FIG. 11-A FIG. 11-B

Photomicrographs, at low and high magnification, showing necrosis in cartilaginous tissue without previous calcification (*a*, *b*, and *c*); *d* shows the transition of cells from tumor to cartilage.

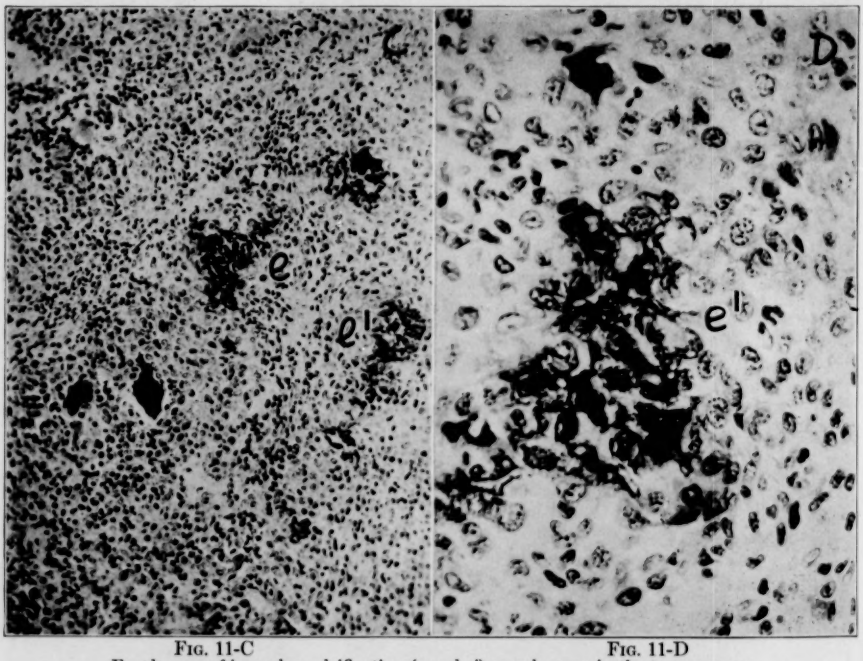

FIG. 11-C FIG. 11-D

Focal areas of irregular calcification (*e* and *e'*) may be seen in the tumor mass.

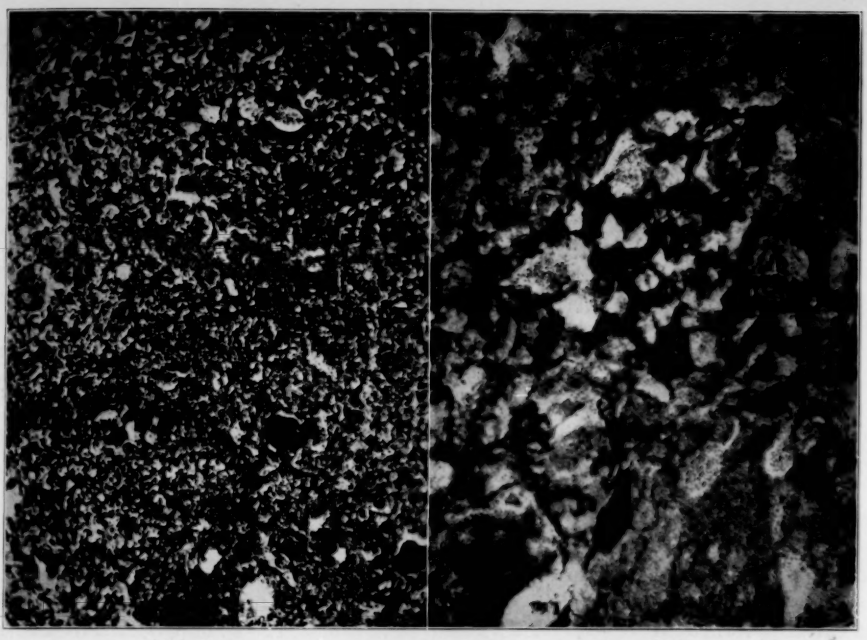

FIG. 12-A FIG. 12-B

Photomicrographs showing the reticulohistiocytic nature of most of the stromal cells, ramified or amoeboid in form. The Rio Hortega stain for reticulo-endothelial elements has been used.

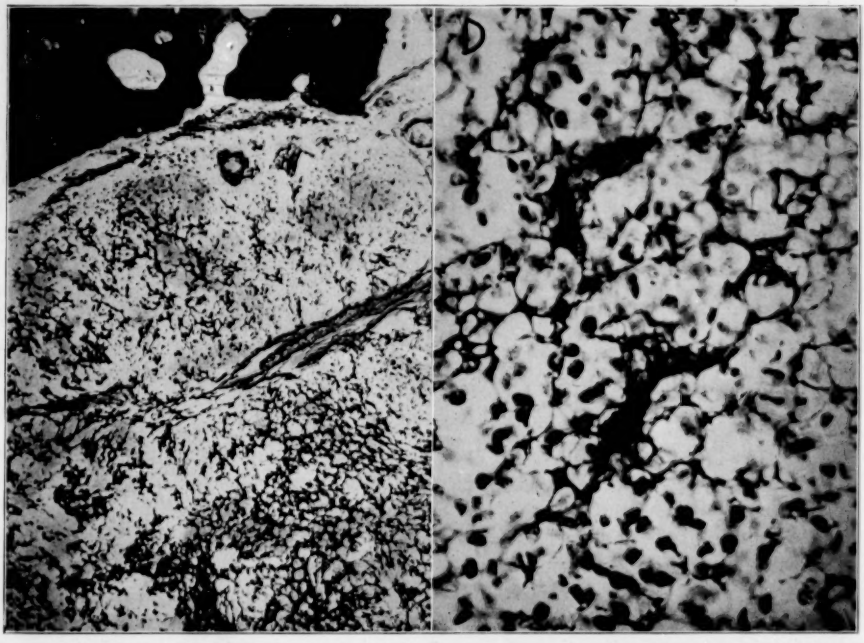

FIG. 12-C FIG. 12-D

Photomicrographs, at low and high magnification, showing the richness of reticular fibrils (Rio Hortega silver stain).

curettement, bone chips, and roentgen irradiation in one case (Case 5); resection and grafting in one case (Case 2); roentgen therapy alone in two cases (Cases 1 and 4). In the cases treated by roentgen therapy alone, surgery was contra-indicated in one because of infection of the wound resulting from the biopsy, and in the other because of the location of the lesion (femoral head and acetabulum). One patient was not treated and was lost to follow-up.

The conservative therapy used proved adequate. When the tumor invaded a joint, the important goal of treatment was to maintain continuity and function of the limb. In one case, resection of a lesion in the proximal epiphysis of the tibia and fusion of the knee joint by grafting was done; in another, where the acetabulum and femoral head were involved, roentgen therapy followed by subtrochanteric osteotomy was the treatment administered.

The majority of our patients did well under all the types of conservative therapy enumerated. No end-result report was obtained in Case 7; follow-up on our other cases ranged from two to twelve years. Five patients were well five or more years after treatment. The other two were well two and three years after treatment respectively.

DISCUSSION

We believe that the basic cell of this tumor is a reticulohistiocytic cell with a tendency to differentiate into chondroblastic tissue and then into cartilage. The basic stromal cell, and not the giant cell, establishes the difference between this group of tumors and giant-cell tumors. In the latter, fibroblastic differentiation may be seen, but never the sequence of cartilage formation. Kolodny interpreted these tumor cells as newly formed cartilage cells, associated with the absorption of misplaced islands of cartilage. Geschickter and Copeland [6] and later Jaffe and Lichtenstein regarded the tumor cell as a chondroblast, occurring as a perversion or acceleration of normal endochondral ossification processes. Our interpretation of the basic tumor cell as reticulohistiocytic is based primarily on the observation of all stages of transition between the tumor cell, the chondroblast, and cartilage, and on the presence, evident by silver stains, of reticulo-endothelial elements and reticulin fibers surrounding the tumor cells and chondroblastic tissue.

That the tumor is benign seems indicated from the course of our cases following treatment. The absence of atypical mitoses and infrequent normal mitoses seem to bear out this conclusion. However, the possibility of malignant transformation of this tumor cannot be eliminated. Geschickter and Copeland [7, 8] described fifteen fatal cases. These were primarily metaphyseal in origin, in contradistinction to the cases of Jaffe, Lichtenstein, and our own, which were primarily epiphyseal. While Geschickter and Copeland originally considered most of these tumors to be malignant [7], they now hold that both benign and malignant varieties exist [8]. Differentiation of these may be exceedingly difficult, both clinically and histologically. Further experience with this tumor may help resolve this difficulty. Our own experience with this lesion does not include malignant instances.

CONCLUSION

Epiphyseal chondroblastomata are tumors of bone, occurring in the adolescent or early adult age group, involving the epiphyses of bones.

The origin of this tumor is considered to be a reticulohistiocytic cell which differentiates into chondroblasts and then into cartilage. In the eight cases of this tumor reported, conservative therapy was curative in all cases treated.

If the lesion has penetrated the epiphysis and injured the joint cartilage, we consider it should be excised and followed by bone grafts in order to make up for loss of substance and maintain the continuity of the limb.

When a surgical approach is impossible, roentgen therapy may succeed in curing the lesion.

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AN ANALYSIS OF DEATHS ON AN ORTHOPAEDIC SERVICE

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The following is a survey of the mortality occurring during the hospitalization of patients on the Orthopaedic Service of St. Luke's Hospital over the ten-year period 1939 through 1948.

Of the 4,787 patients admitted during this period, seventy-two died, representing a mortality rate of 1.50 per cent. There were a total of 4,404 operative procedures performed upon these patients. There were forty-nine deaths among those patients who had had operations, giving a mortality rate of 1.11 per cent. Ten of these deaths occurred within forty-eight hours after the operation, an operative mortality rate of .23 per cent. The remaining thirty-nine deaths of patients who had undergone operations occurred

some time after the forty-eight-hour postoperative period, a mortality rate of .88 per cent. Somewhere between these two figures lies the true percentage of operative mortality.

Only one child under fifteen years of age died. Her death was caused by a tuberculous meningitis eight and one-half months after operation.

Number of Deaths Grouped According to Cause

Inanition: Among the seventy-two deaths, fourteen were directly attributable to inanition. This includes the factors of advanced age, diminished blood proteins, severe nutritional and feeding problems, advancing weakness, and pressure sores. Thirteen of these patients died before an intensive study had been made of blood-protein levels in the aged patient as reported elsewhere.[1]

Pneumonia: Eleven patients died from pneumonia. Two of these had lobar pneumonia, while nine had bronchopneumonia together with severe inanition. Here again the tremendous importance of the factors classed as inanition is shown.

Cardiac Disease: Severe cardiac disease accounted for the death of six patients. Four of these patients were admitted with severe arteriosclerotic heart disease, and one with severe mitral stenosis. The last death in this group was caused by coronary occlusion.

Malignant Tumors: The deaths of nine patients were caused by some form of malignant tumor. The tumors included a primary carcinoma of the liver, carcinomata of the sigmoid colon, breast, bladder, and adrenal glands, and one multiple myeloma.

Pulmonary Embolism: Pulmonary embolism caused six deaths, making a mortality rate of 0.13 per cent. Emboli developed in three patients who died following trochanteric fracture of the femur and one following an intracapsular fracture of the femoral neck. At the postmortem examination it was found that emboli developed from the uninvolved extremity in two. One death followed a trisacral fusion and one followed a McMurray osteotomy. In most instances, the embolism occurred within twelve days; however, one occurred as late as fifty-two days after the operation. There have been emboli but no deaths from emboli since 1946, because of the use of anticoagulants.

Wound Infection: Seven patients died as the result of wound infection. Four of these patients had fractures at the hip treated by an operative procedure. In one of these gas bacillus infection developed and the patient died eleven days after the operation with the infection under control. In this patient death was due to renal failure. In three tuberculous patients with bone and joint lesions, death was caused by wounds breaking down and becoming secondarily infected.

Diabetes: Severe and uncontrolled diabetes caused four deaths.

Cerebral Vascular Accidents: Six patients had fatal cerebral accidents.

Tuberculosis: Advancing tuberculous disease caused three deaths. One death occurred from progressive pulmonary disease and another from meningitis. One patient died from advancing Addison's disease.

Miscellaneous Causes:

Two patients died after traumatic transsection of the spinal cord in the cervical area. One had been admitted with quadriplegia, while the other had been admitted with a fracture-dislocation of the cervical spine for which skull traction was applied. This patient had delirium tremens and severed his cord through the fracture site by attempting to leave his bed.

Two deaths were caused by uncontrollable shock, one by a ruptured peptic ulcer, and one by uraemia from severe kidney dysfunction. The patient who died following rupture of a peptic ulcer had been admitted with osteomyelitis of the spine and bilateral large psoas abscess. He had been hospitalized for four months when abdominal pain developed and he died of peritonitis secondary to a ruptured peptic ulcer.

Mortality in Relation to Condition Treated

Intracapsular Fractures of the Femur: There were 160 patients with intracapsular fractures of the femur and of these nineteen died during their hospital stay, giving a mortality rate of 11.8 per cent. Of these, four had not been operated upon. Of the fifteen who died following operation, there were four who died within forty-eight hours, an operative mortality of 2.5 per cent. Of these four the average age was eighty years. Of those who died six days was the average time before admission to the Hospital after the fracture, which represents a loss of extremely precious time.

Intertrochanteric Fractures of the Femur: There were 147 patients with intertrochanteric fractures of the femur. Of these, thirty died during their hospital stay, a mortality rate of 20.48 per cent. A mortality rate of this magnitude requires some explanation. The average age of these patients was seventy-five years, ten years older than the average age of those patients with intracapsular fractures. Of these 147 patients, thirty-three were treated in Russell traction; ten died, a mortality rate of 30.3 per cent. There were 114 patients with intertrochanteric fractures who had been treated by reduction and surgical internal fixation; twenty of these died, a mortality rate of 17.5 per cent. This group shows a significant reduction in the mortality rate; there were only two actual postoperative deaths occurring within forty-eight hours after the operation among these 114 patients treated by internal fixation, which gives a postoperative mortality rate of 1.75 per cent.

The causes of death in elderly patients with fractures at the hip, trochanteric or intracapsular, are primarily poor nutrition and circulatory conditions, both of which are present prior to the injury. Many of them are also unable to compensate for the altered position and the diminished activity which the fracture demands.

Of the forty-nine deaths among patients with hip fractures, a little over 50 per cent. succumbed to pneumonia and inanition. Twenty-five per cent. died because of cardiac decompensation, myocardial infarction, and cerebral vascular accidents. The remaining deaths were attributed equally to pulmonary embolism, carcinoma, and wound infection.

At the present time, early internal fixation of both the intracapsular and intertrochanteric fractures of the femur as a primary life-saving procedure is advocated, except in the occasional patient who reaches the Hospital practically moribund.

Miscellaneous: The remaining deaths were caused as follows—six deaths from multiple fractures; four from bone and joint tuberculosis; and nine from malignant diseases. Four deaths occurred among patients who had been admitted with other bone and joint conditions.

SUMMARY

1. Forty-nine (68 per cent.) of the deaths occurred in elderly patients with fractures about the hip joint.

2. Excluding those patients with fractures at the hip, there were 4,480 patients admitted. Twenty-three died during hospitalization, a mortality rate of 0.51 per cent. Four deaths were actual postoperative deaths, a mortality rate of 0.086 per cent.

3. When patients who are aged, debilitated, diabetic, with cardiac disease, or presenting malignant tumors are hospitalized, some deaths are expected.

4. Reduction of hospital mortality may be achieved by special attention to nutritional problems, good surgical judgment and technique, the use of antibiotics, the judicious use of anticoagulants, and the meticulous care of coexisting medical and surgical problems.

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CERVICAL SPONDYLOLISTHESIS

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Congenital anomalies of the cervical spine are not uncommon, especially those involving fusion between the bodies of the cervical spine or between the posterior arches. Hadley [1] enumerated a number of congenital lesions occurring in this area; among the lesions are unilateral pedicle defects. We were unable, however, to find any record of a

FIG. 1

FIG. 2

Fig. 1: Anteroposterior view of the cervical spine reveals a spina bifida in the sixth cervical vertebra. The body of the sixth cervical vertebra partially overlaps that of the seventh cervical vertebra.

Fig. 2: Lateral view of the cervical spine reveals evidence of spondylolisthesis between the sixth and seventh cervical vertebra.

case of bilateral pedicle defects with resulting spondylolisthesis. Such a case is here presented.

E. H. M., a white male, nineteen years old, was employed as an x-ray technician in the Army. He first began to have symptoms at about one o'clock in the afternoon on August 7, 1945, after a game of basketball which had lasted about three hours. The symptoms were mild aching in the back of the neck and a mild headache in the suboccipital region bilaterally. The aching pain was accentuated by twisting the head to either side. There was no radiation of the pain into the thoracic area or into the shoulders, arms, or hands.

The patient's past history was of no particular significance. He had been active in basketball and football in school until 1942. He could recall no particular trauma to the cervical spine.

Physical examination on admission to the Hospital revealed a well developed, well nourished, slender, white male, six feet two inches in height, who did not appear to be in any distress. There were no noteworthy findings on inspection of the neck, except for the fact that the head and neck were carried forward in relation to the rest of the spine to compensate for a moderate degree of dorsum rotundum which was mainly confined to the upper portion of the thoracic spine. There was no muscle spasm or any tenderness in the cervical spine.

FIG. 3

FIG. 4

Fig. 3: Left oblique view of the cervical spine shows a complete defect in the pedicle of the sixth cervical vertebra.

Fig. 4: Right oblique view shows a small, thin, incomplete pedicle on the right side of the sixth cervical vertebra.

Between the fifth and the sixth cervical spinous processes, there was a definite step-off palpable. Active and passive motion in rotation produced pain in the back of the neck which radiated upward to the suboccipital area. This manoeuvre was associated with a sensation of pressure in the suboccipital area. There was no pain in the cervical area on flexion and extension and lateral bending, carried out actively, passively, or against resistance. There were no sensory, motor, or reflex disturbances in the upper or lower extremities. A large indirect inguinal hernia on the right side was asymptomatic. There were no other physical findings of note.

Roentgenograms (Figs. 1, 2, 3, and 4) were taken in the anteroposterior, lateral, and both oblique projections of the cervical spine. Figure 2 shows the spondylolisthesis. The sixth cervical vertebra and the superincumbent vertebrae were displaced forward on the posterior arch of the sixth cervical vertebra and on the seventh cervical vertebra. At this level, there was an increase in the cervical lordosis. The defects appeared to be in the pedicles of the sixth cervical vertebra. The articular pillars of the sixth cervical vertebra were underdeveloped and were decreased in height, and the articular pillars of the fifth cervical vertebra were not fully developed. The neural canal was angulated at this level. There was a spina bifida of the sixth cervical vertebra, and there was a bulge in the soft tissues anterior to the body of the sixth cervical vertebra.

In June 1951, the patient reported that he is without symptoms. He is working in a foundry and does considerable shoveling.

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CORRECTION

In the article by Dr. Henry Milch on Triphalangeal Thumb, published in *The Journal* for July 1951 (Vol. 33-A, pages 692–697), four cases of this deformity were reported.

The patient whose history is presented as Case 1 was seen by Dr. Milch in the Out-Patient Clinic at the Hospital for Joint Diseases on January 2, 1943.

By a coincidence this man was one of the group found by Dr. Paul W. Lapidus in examination of draftees at the New York Recruiting and Induction Station. This case was included in the six cases reported by Dr. Lapidus and Lieut. Col. Frank P. Guidotti in their article published in *Archives of Surgery* (Vol. 49, pages 228–234, October 1944).

The article by Dr. Milch published in the July *Journal*, therefore, increases the reported cases by three, rather than by four.

OVERLAPPING SPLIT-THICKNESS SKIN GRAFTS FOR DEEP CAVITIES

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The modern trend in the treatment of osteomyelitis is toward thorough débridement and primary closure under the protection of antibiotics. However, this is not always possible, for adequate skin for the primary closure without tension may not be available. The bone should be covered on all sides with living soft tissue to stop the cycle of low-grade infection, reaction, and fibrosis, and to avoid poor vascularity with the continuance of a locus of lowered resistance. Split-thickness skin-grafting offers an attractive method for a rapid covering of such an exposed area.

From 1902, when Lord reported the results from the use of Thiersch grafting, down through recent extensive military experience as exemplified by the work of Kelly, Rosati, and Murray, various methods of skin-grafting have been used to accomplish coverage. Free skin-grafting has been practical only where a shallow, relatively smooth cavity exists after saucerization. The methods previously used are relatively impractical when there are undercut bone surfaces or deep irregular cavities. Grafts applied to such surfaces often result in unsatisfactory "takes", since poor apposition of skin to the underlying tissue occurs because of tenting or wrinkling. The sacrifice of viable bone, merely to produce a shallow surface for grafting, may needlessly impair structural stability.

FIG. 1

Osteomyelitic area Saucerization Débridement

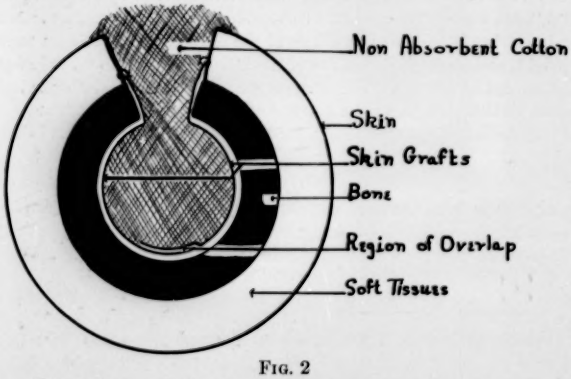

FIG. 2

Diagrammatic drawing illustrating the procedure.

The method herein presented makes use of débridement rather than saucerization (Fig. 1). Although the details of this method may not be original, we have been unable to find previous references to it in the literature.

The preparation of the osteomyelitic area for split-thickness skin-grafting is accomplished by means of a thorough débridement followed by a smoothing of the surfaces with motor-driven, rotatory files. Even though immediate split-thickness skin-grafting is possible after débridement, it is better to be assured of the underlying vascularity by waiting from seven to ten days for good early granulation tissue to form. For, if granulation tissue formation is not satisfactory in all areas of the wound at that time, the continued presence of questionable tissue in the wound must be presumed. Since the "take" of a split-thickness

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skin graft on this type of base is doubtful, a repetition of the débridement is indicated until a satisfactory recipient surface is secured.

Two split-thickness skin grafts, each slightly longer than and two-thirds to three-quarters as wide as the area to be grafted, are obtained,—preferably with a Padgett dermatome. One edge of each graft is sutured to each of the long edges of the wound by interrupted sutures. The free ends of the graft are allowed to fall loosely into the cavity. Since each graft is a minimum of two-thirds as wide as the area to be grafted, there will be an appreciable overlap at the bottom of the wound. The cavity is then packed with wet cotton, and, as further packing is added, the entire mass will conform accurately to the contour of the wound, carrying with it the free ends of the two skin grafts. This is possible because only one side of each graft is fixed, and free sliding motion occurs at the site of the overlap to make up the extra circumferential distance (Fig. 2). This avoids both tenting and wrinkling. No concern need be felt for the overlap region since the more superficial of the two layers will slough but will not inter-

FIG. 3-A

FIG. 3-B

FIG. 3-C

Fig. 3-A: Preoperative state. Shown in the photograph are draining sinus and scars of previous operative attempts. The wound had been draining almost constantly for four years. The patient complained as well of a continuous aching pain which became more severe at night.

Fig. 3-B: State after débridement but before grafting. Shown is the irregular cavity with deep indentations caused by the removal of all diseased bone with no sacrifice of viable bone.

Fig. 3-C: Appearance one year later after overlapping split-thickness skin grafts had been applied. The grafts have been stable, and the patient has no pain and no drainage.

fere with the "take" of the deep layer. When the wound has healed, the overlap region is revealed by a scarcely noticeable ridge.

Because the grafts are uniformly large sheets, a smooth, completely covered surface results. There is no need to use molds, stents, or complicated piecing of grafts, for the procedure is technically easy; it is even applicable to deep cavities with overhanging edges.

Although the resulting split-thickness skin graft may be considered an end result, it is possible at any time in the future to remove it and to have a clean surface for subsequent reconstruction.

This procedure has been successfully used, to date, in four cases. These cases have been followed up to two years, and thus far the grafts have proved serviceable and stable (Figs. 3-A, 3-B, and 3-C).

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LETTER TO THE EDITOR

A recent British volume of *The Journal of Bone and Joint Surgery* carried an article by Mr. H. Osmond-Clarke in which reference is made to the following books:

(1) Sir Arthur Keith: Menders of the Maimed;

(2) H. A. Harris: Bone Growth in Health and Disease.

I feel that these two volumes should be in the possession of every orthopaedic surgeon. For the past five years I have tried in vain to purchase a copy of each of these books. Both the medical book stores and the collectors of rare books have been unable to find a copy which could be purchased.

I am writing to see if *The Journal* could be of any assistance in finding copies of these books. I am sure that, if copies were available, they would be sought after by many other orthopaedists. If copies are not available, is there any possibility that a limited reprint of these two books be undertaken?

June 12, 1951

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CUTANEO-OSTEOVESICAL FISTULA

Report of a Case Following Fracture of the Pelvis, Rupture of the Bladder, and Hip Fusion*

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Fractures of the pelvis continue to be among the most serious of all skeletal injuries; the mortality rate is high (8.8 per cent. among 1,142 cases collected by Lam), and the complications are many. Much has been written concerning the primary urinary-tract complications of fractures of the pelvis but little in regard to other untoward sequelae. The following case is reported because of the multiple complications secondary to a severe fracture of the pelvis which culminated in a cutaneo-osteovesical fistula, two and one-half years after the original injury.

J. M. J., a white machinist, twenty-eight years old, was struck by an automobile on October 26, 1946, and was taken to a local hospital where he was treated for shock. He was found to have sustained extensive comminuted fractures of the entire right side of the pelvis, involving the acetabulum, ilium, ischium, and the pubic rami, with medial displacement of the right femoral head (Fig. 1). Since rupture of the bladder was suspected, surgical exploration was done shortly after his admission. Large amounts of blood and

FIG. 1

X-ray of pelvis taken several days after repair of bladder and urethral rupture. Extensive fractures of the ilium, acetabulum, and pubic rami with central displacement of right hip and displacement of bladder are seen.

* Reviewed in the Veterans Administration and published with the approval of the Chief Medical Director. The statements and conclusions published by the author are a result of his own study and do not necessarily reflect the opinion or policy of the Veterans Administration.

urine were found along the left retroperitoneal gutter and in the prevesical space, but no intraperitoneal extravasation was found. Extensive comminuted fractures of the bones of the right pelvis, with displacement in all directions, were noted. One large fragment from the superior pubic ramus was found lying transversely across the pubic arch and had apparently caused a five-centimeter laceration in the anterior aspect of the posterior urethra and bladder wall. The laceration was sutured, the bladder was decompressed with a suprapubic tube, and the space of Retzius was drained.

Two weeks later, the fractures of the pelvis and the displacement of the hip were treated by placing a Steinmann pin through the greater trochanter of the right femur to provide traction. A double plaster spica, incorporating the pin, was maintained for a period of ten weeks. At the time of his discharge on February 8, 1947, there was "no evidence of bone infection" and cystoscopic examination revealed the bladder to be "in good condition".

The patient was first admitted to this Hospital on March 11, 1947. He complained of right foot-drop, pain in his right hip, and numbness over the lateral aspect of his right leg.

Roentgenograms disclosed aseptic necrosis of the head of the right femur, while the neurological examination confirmed the presence of a common peroneal palsy.

Because recovery did not occur after three months had elapsed, a sciatic neurolysis was performed on

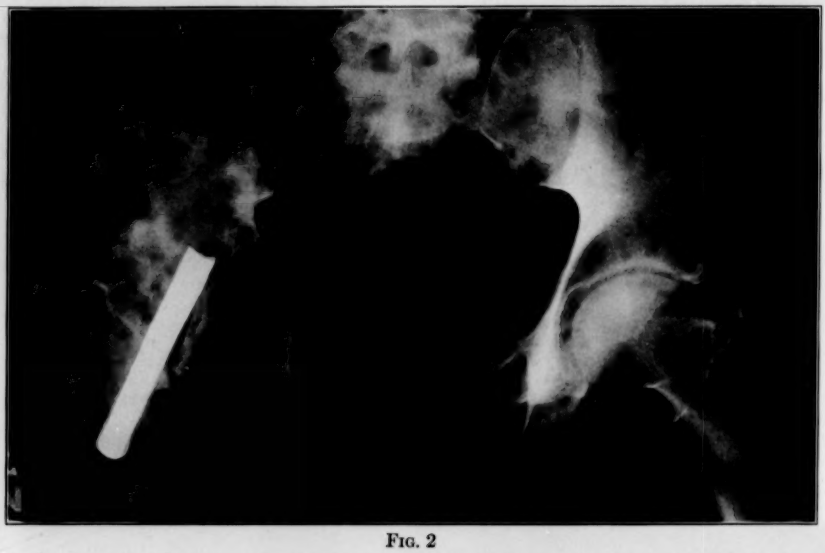

FIG. 2

X-ray of pelvis following arthrodesis, showing Smith-Petersen nail in good position.

June 11, 1947. The nerve was found to be adherent to the ischium in the region of the sciatic notch, apparently at the site of fracture. Following this procedure, the patient had an excellent return of sensation and of function of the extensor muscles. During the next six months, he was walking with the aid of a foot-drop brace and crutches.

Because of persistent pain in the right hip and roentgenographic evidence of the progression of the aseptic necrosis and traumatic arthritis of the right hip, an intra-articular (Watson-Jones) hip fusion was performed on January 6, 1948. A Smith-Petersen nail was driven through the neck of the femur into the superior portion of the acetabulum (Fig. 2). No guide wire was used, and no difficulty was encountered in the operation. A single spica was applied after the operation and was maintained for the next fourteen weeks. After the operation, wound infection, secondary to *Staphylococcus aureus*, developed; therefore, on February 28, 1948, the wound was debrided through a window in the cast. Drainage persisted despite chemotherapy, antibiotics, supportive measures, and a second débridement with sequestrectomy. From January to July 1949, the patient had occasional slight urgency but had no other urinary complaints. Urinalyses revealed acid urine and persistent pyuria, but the urine was found repeatedly to be sterile with the exception of two occasions when *Staphylococcus aureus* and *Pseudomonas aeruginosa* were cultured from the specimen. Cystoscopy was essentially indeterminate except for disclosing a patulous bladder neck and a scarring at the dome of the bladder. During the ensuing ten months, the patient required an additional incision and drainage

for wound infection of the hip. Otherwise he was well and had only rare and transient episodes of urgency in urination.

In May 1949, he was re-admitted to the Hospital because of an exacerbation of the wound infection. Roentgenograms revealed that the Smith-Petersen nail was displaced laterally. On May 18, 1949, an incision was made, drainage was performed, and the nail, which was found lying subcutaneously in a pool of pus, was removed. The long channel in the femoral neck, formerly occupied by the Smith-Petersen nail, was curetted and packed lightly with vaselin gauze. The wound was left open. Culture disclosed the presence in the pus of *Staphylococcus aureus*, *Alcaligenes faecalis* and *Streptococcus faecalis*.

On the fourth day after the operation, irrigation with chloresium solution through a catheter in the wound was started. On the tenth day, following irrigation of the sinus tract, the patient voided urine stained green with chloresium. Urine culture was negative. The patient had slight urgency but had no other urinary symptoms. On June 2, 1949, cystoscopy disclosed slight hyperaemia of the right side of the bladder, but no ulceration, fistulous opening, or other abnormality was noted. On the twentieth day, diodrast was injected into the cutaneous opening and roentgenograms revealed a fistulous tract, extending through the area previously occupied by the nail, coursing through the head of the femur and fovea centralis, and entering the true pelvis along the linea terminalis where it penetrated the floor of the bladder (Fig. 3). Two days later, urethrocystograms and voiding cystograms proved that the fistulous tract did not fill before, during, or after micturition. There was dilatation and distortion of the prostatic urethra, particularly about the seminal colliculus. Methylene blue, given orally, and indigo carmine, administered parenterally, stained the urine but did not appear on the wound dressing. During the next three weeks, the thigh wound healed gradually, and the sinus tract could no longer be demonstrated in roentgenograms after diodrast injection.

FIG. 3

Cutaneo-osteovesical fistula appears in the roentgenogram following injection of diodrast.

Five months later, the patient entered the Hospital for observation. His only urinary symptoms had been transient urgency and nocturia once or twice each night. He experienced a dull aching pain in the right hip after three or four hours of activity. Sexual function had been normal. The examination revealed a satisfactory hip fusion and absence of abnormal neurological findings in the right leg. There were numerous pus cells in the urine and culture was positive for *Staphylococcus aureus*. This organism proved resistant to 0.09 microgram of penicillin per cubic centimeter. At cystoscopy, there was mild diffuse hyperaemia of the bladder, and the bladder neck appeared rigid. Cystography failed to reveal the presence of a sinus tract. Excretory urography showed a satisfactory concentration of dye bilaterally with a normal outline of the upper urinary tract. The patient was treated with two grams of streptomycin daily for ten days, following which the urine became sterile and the pyuria vanished. Four months later the patient was still asymptomatic, and the urine was clear and uninfected.

DISCUSSION

It is of interest that this bizarre fistula developed more than two and one-half years after the patient's original trauma. It was felt that the fistula was the result of the original bladder and urethral perforation with post-traumatic fixation of the vesical neck to the pelvis; and it seemed also that the subsequent osteomyelitic process burrowed through the fracture site and into the bladder in the region of the primary tear. Since a guide wire was not used in placing the nail, it can be assumed that no additional bladder injury occurred after the original trauma. The healing of the fistula occurred following adequate drainage of the osteomyelitis and the soft-tissue abscess of the hip. The absence of bladder calculi,

obstruction at the vesical neck, and additional sequestra favored the prompt resolution.

An osteovesical fistula is a rare complication of injuries of the pelvis and its adnexa. The majority of the cases reported have been attributed to hematogenous osteomyelitis of the pubis and to pelvic osteomyelitis complicating suppurative arthritis or tuberculosis of the hip joint. In 1933, Hepler and Eikenbary were able to collect only ten cases of spontaneous perforations of the bladder secondary to osteomyelitis of the pelvis. In the main, these occurred in children and young adults in whom the osteomyelitis was hematogenous, or secondary to pyogenic hip disease. Hematogenous osteomyelitis develops most commonly in the pubic bones of children, and the proximity of this portion of the pelvis to the bladder predisposes to the development of osteovesical fistulae. Mathé reported three cases of vesical fistulae following traumatic rupture of the bladder associated with fractures of the pelvis. All of his patients improved after the removal of sequestra and bladder calculi or the excision of the fistulae. Mathé presented a detailed discussion of the pathogenesis of these fistulae. He stated that the leakage of urine in cases of bladder-neck perforation may cause osteomyelitis of the pelvis, which in turn may communicate with the bladder. He observed that when chronic cystitis and persistent pyuria develop in patients who have previously sustained fractures of the pelvis with rupture of the bladder, osteomyelitis may be suspected as a possible late complication. Finally, he emphasized the principles of accurate closure of primary bladder lacerations and adequate drainage of the perivesical extravasations as prophylaxis against the development of secondary osteomyelitis of the pelvis.

Perusal of the literature has failed to reveal reports of an osteovesical fistula following hip-nailing, either for arthrodesis or for fractures of the femoral neck, although perforation of the bladder may occur during the insertion of guide wires for hip-nailing following which osteomyelitis of the femur or of the acetabulum may occur.

Finally, it should be mentioned that, in the future, osteovesical fistulae may be seen as a complication of retropubic surgery. While osteitis pubis is admittedly rare and is usually a self-limited disease which seldom culminates in frank osteomyelitis, it is conceivable that rarely an involucrum may develop, which can penetrate the bladder in the same manner as those which have been reported following hematogenous osteomyelitis of the pubis.

SUMMARY

The case reported demonstrates multiple complications of a fracture of the pelvis with central displacement of the hip, culminating in a bizarre cutaneo-osteovesical fistula two and one-half years after the original trauma.

Such fistulae following hip fusion produced by internal fixation or following hip-nailing for fractures of the femoral neck are singularly rare.

The fistula in this case was demonstrated by injection of the cutaneous ostium but not by cystography.

The treatment of such fistulae should consist in adequate drainage of abscesses, removal of sequestra, establishment of adequate bladder drainage, and control of infection by chemotherapeutic and antibiotic agents.

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EVALUATION OF RADIO-ACTIVE ISOTOPES AS AN ADJUNCT TO SURGICAL DIAGNOSIS AND THERAPY*

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The interest of investigators in all the specialties has been stimulated through the rapidly expanding program of medical research in the field of radio-active and stable isotopes. An increasing number of radio-active isotopic materials, both of a simple and a complex nature, are becoming available for use in this country and abroad.

Prior to the work of Curie and Joliot in 1934, the administration of ionizing radiations to tissue was largely through x-rays, radium, or the daughter elements of radium. Therapy was carried out by both x-rays and radium, while diagnosis was limited to roentgenographic studies.

Today, the problems of diagnosis and treatment include a biochemical approach for which a large number of chemical radio-active isotopic preparations are available. Studies with these substances can also be applied to the many processes of growth, intermediate metabolism, conversion, and absorption.

Tracer and diagnostic problems are possible of solution because appropriate radio-active isotopes, when used in minute quantities, are readily identified by special instruments; yet their emanations are not of sufficient intensity to damage tissue or derange function.

From the point of view of treatment, radio-active isotopes pose complex problems. Tremendous efforts are being made to evolve radio-isotopic compounds which will localize in a tumor and yet not concentrate in other tissues of the body in sufficient quantity to limit seriously the localized therapeutic dosage which can be administered.

Radio-isotopes may contain alpha rays and also beta or gamma rays or both. The alpha particle has a range in tissue of only a few millimeters before its energy is entirely dissipated near the site of application. Radio-active isotopes which emit alpha rays are found primarily in those radio-active elements which are bone-seekers by chemical choice, such as radium and plutonium. These substances, however, are highly toxic, have long physical half-lives, and have no practical value.

Radio-active elements which emit beta rays produce emissions which are particulate and which penetrate from one millimeter to several centimeters. These can be used effectively for tracer or diagnostic studies as well as in therapy.

The range of gamma rays, when emitted from a radio-active element, is in terms of feet. Since the effect of such rays cannot be localized entirely in a given area, their internal application is comparable to that of radium (or radon) which is applied interstitially.

In radium therapy, the beta rays are filtered out to avoid escharotic effects in applying single sources of radium or radon (tubes and needles) over a wide range of therapeutic uses. This is done in order to gain the maximum dosage effect from the penetrating gamma rays. The use of radio-isotopic beta-ray irradiation for extensive tracer and therapeutic purposes internally is a complete reversal of technique. Where a radio-isotope contains a gamma-ray component in addition to the useful beta-ray irradiation, such as radio-active iodine (I^{131}), the gamma-ray irradiation permits the localization or measurement of the element by special instruments at adequate distances outside the body. Radio-isotopes which contain only gamma rays are effective agents when it is possible to concentrate them sufficiently in local areas, although their action simulates the focal application of interstitial radium or radon. The effect of the gamma rays occurs at some distance from their source along the paths of the quanta of energy.

If a radio-isotope is to be used for biological or medical purposes, it must meet many exacting requirements. The chemical substance must be non-toxic in the doses required and must be free from impurities or radio-ionizing daughter substances. The isotope must also have a reasonably short radio-active half-life, so that the radiation will not persist beyond the desired period; and it must not localize in a damaging concentration at areas other than those to be treated. Its half-life, however, must be of sufficient duration to allow its use in conversion to useful compounds and to permit transportation from the laboratory of its source to the clinic where it is to be administered. In spite of the many problems encountered, radio-isotopes have added another means of improving the diagnosis and therapy of certain diseases and neoplasms.

It is the purpose of this communication to present an evaluation of current investigative work with radio-active iodine and radio-active phosphorus as well as with other radio-isotopes of practical interest to the orthopaedic surgeon. One cannot appreciate the possibilities presented by the use of radio-isotopes unless some departure is made from the study of ionizing irradiations as applied strictly to the osseous structure.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 29, 1951.

Two general types of investigation with radio-isotopes in medicine are being carried out:

1. *Tracer and Diagnostic Studies:*

Because of the extreme sensitivity of detection and the unique specificity of radio-isotopes as tags, they become of tremendous value in identifying certain types of cells. They permit the study of the process of nutrition and growth (normal and abnormal), of absorption, of conversion, and of the assimilation and the excretion of nutritive compounds in animal and man.

2. *The Use of Radio-Isotopes in Therapy:*

Radio-isotopes used in therapy surmount a complicating group of factors. The biological effects of radio-isotopes vary with the characteristics of the element used. Specific absorption of a radio-active element by the affected organ or tissue often does not exist; conversely, the marked ability of some organs to concentrate a certain element may limit the amount of the radio-isotope which can be given. Unfortunately, so far, special localization has been limited mostly to normal or physiologically deranged organs. In spite of these and other problems, radio-isotopes are now being employed to supplement, and occasionally, to replace x-rays and radium in the treatment of cancer and allied diseases. There are relatively few artificial radio-active isotopes (of some 750) which have practical application in the medical field at the present time.

Radio-Active Iodine (I^{131})

Of all the available isotopes, radio-active iodine (I^{131}), with beta rays of 0.595 m. e. v.* and gamma rays of 0.367 m. e. v. and 0.080 m. e. v., is thought by many to have the greatest diagnostic and therapeutic value. The short half-life of eight days of iodine (I^{131}) and the problems of accurate assay have for a long time prevented its acceptance in clinical use. It is now being employed extensively, however, in both the diagnosis and therapy of thyroid diseases. Its value as a biological tracer has been exemplified in patients with cancer of the thyroid, in whom, through its use, it can be demonstrated that there is a fundamental difference between the normal and cancerous tissue of the thyroid gland. Radio-active iodine, which emits both beta and gamma rays, has specificity for thyroid tissue and, therefore, becomes an excellent tag for studying diseases of the thyroid gland. The rate of its deposition may be followed by simply holding a Geiger-Müller counter at an appropriate distance from the thyroid gland outside the body. The Geiger-Müller counter is a special instrument by which all ionizing radiations may be detected and, through arrangement with electronic circuits, radio-active emissions can be counted and recorded.

Early clinical investigations with radio-active iodine were made by Hamilton and Soley; Hertz, Roberts, and Evans; and Means. These investigators studied not only the uptake of iodine in animals and in patients who had undergone thyroidectomy, but also the rate of the excretion of iodine in such patients, as well as in normal persons. They further studied the uptake of iodine by the thyroid and the excretion of iodine in patients with various diseases of the thyroid. Many other investigators have since studied this substance along similar lines, perfecting the methods of determining the metabolism of the radio-active element and crystallizing the evaluation of its usefulness as a diagnostic and therapeutic agent.

By the use of tracer doses of from 25 to 100 microcuries of radio-active iodine, it can be shown that hyperthyroid individuals usually concentrate over 50 per cent. of the radio-active material in twenty-four hours, as contrasted with 10 to 20 per cent. in normal individuals. Studies have also been made on the metabolism of radio-active iodine (I^{131}) and its conversion to protein-bound thyroxine. It has been found that persons with hypothyroidism have a conversion rate of from 6 to 10 per cent., whereas those with hyperthyroidism have a conversion rate of from 50 to 90 per cent. in severe thyrotoxic states.

Other uses of radio-active iodine as a tracer are demonstrated in the work of Chapman, Corner, Robinson, and Evans, who have studied the transfer of radio-active iodine from the mother to the human foetus. Since they observed that during the first twelve weeks of pregnancy the foetus does not compete with the available maternal iodine supply, they concluded that a woman during this phase of pregnancy may safely undergo therapy with radio-active iodine.

Frantz, Quimby, and Evans have extensively studied a series of thyroid carcinomata with radio-active iodine (I^{131}). In their experience, malignant adenomata and some adenocarcinomata tend to show a variable functioning concentration of radio-active iodine (I^{131}), while papillary carcinoma, Hürthle-cell carcinoma, and giant-cell and spindle-cell carcinomata do not show uptake of the element. They hold, *sub judice*, the hypothesis that the greater the degree of differentiation, the higher the functional activity.

Rawson, Skanse, Marinelli, and Fluharty have studied the differentiation of function in benign and malignant tumors and in both primary malignant thyroid cancers and their metastatic deposits. Patients on whom thyroidectomy was to be performed were given from 100 to 2000 microcuries of radio-active iodine (I^{131}) one to seven days prior to operation. Surface measurements indicated that the capacity to collect iodine is characteristic of thyroid tissue and that the characteristic function of thyroid tumors to concentrate iodine parallels the degree of differentiation of the tumor. The metastases from the thyroid cancer develop function frequently after the surgical removal of the primary tumor and the thyroid gland. This has been interpreted

* The abbreviation "m. e. v." refers to million electron volts.

as an activation of function in the metastases which had been non-functioning prior to the time of thyroidectomy. Evidence has accumulated that, in both the mixed papillary and adenomatous carcinomata and the malignant adenomata, ablation of the primary focus by an elective total thyroidectomy will enhance the functional or physiological demand for radio-active iodine (I^{131}) at local or distant tumor foci. Such a demand may be further stimulated by the administration of thyrotropic hormone. Frantz and her co-workers have used dosages of from 50 to 100 millicuries of radio-active iodine (I^{131}) in patients with bone metastases. Total cumulative dosages up to 550 millicuries of radio-active iodine (I^{131}) have been reported as being given over a period of ten months by Marinelli, Trunnell, Hill, and Foote.

Trunnell, Marinelli, and their associates have studied twenty-five patients with proved metastases from carcinoma of the thyroid gland (pulmonary and skeletal). They found that it was necessary to remove the thyroid gland in all but one case, in order that the metastases would concentrate sufficient radio-active iodine (I^{131}). Thyroid-stimulating hormone was given to six patients in 30-milligram doses daily for five or more days. This resulted in an increased avidity for radio-active iodine in the metastases of three of the six patients. Thiouracil and propylthiouracil were given over a period of months in ten patients who had undergone thyroidectomy. These patients had metastatic lesions which had already developed an increased avidity for radio-active iodine (I^{131}). The thiouracil drugs, however, resulted in a further pronounced increase in radio-active iodine uptake. It must be pointed out, however, that insufficient time has elapsed to appraise final radiation damage in these patients.

Moore and his associates have demonstrated the selective concentration of diiodo^{131} fluorescein in brain tumors. Radio-active diiodofluorescein can be readily detected at a distance because of the gamma rays present in radio-active iodine (I^{131}). Up to 500 microcuries or more of the drug have been injected intravenously into patients prior to operation. Differential readings, made over the suspected tumor areas and corresponding normal areas, became evident from two to four hours later. It was found that tumors with a volume of 20 cubic centimeters or more could be readily identified under average conditions. If, however, the tumors were accompanied by a large amount of oedema, the entire area of the affected hemisphere gave somewhat higher surface counts, making the exact localization of a brain tumor difficult.

Davis, Martin, and their associates have utilized radio-active diiodofluorescein in the study of 200 patients with the diagnosis of a space-occupying lesion of the central nervous system. The results reveal a 95.5 per cent. accuracy in the diagnosis of lesions which was verified by surgical intervention or was corroborated by pneumography or angiography. This study included a positive radio-active dye test in five of six verified tumors of the spinal cord. The investigators used approximately 1.1 millicuries of radio-active diiodofluorescein intravenously, in an 8 to 10 per cent. sterile solution. They noted, within a minute or two after the injection of the dye, that the radio-activity at the surface of the head was at a maximum and then decreased rapidly over the next ten to thirty minutes. The most significant counting rates occurred within one-half to two hours after the administration of the radio-active dye. At the end of two to four hours, the readings were only confirmatory, for the differential concentrations were no longer striking.

Radio-Active Phosphorus (P^{32})

Radio-active phosphorus (P^{32}) is the isotope of second greatest medical importance and holds considerable interest for orthopaedic surgeons, especially those who are concerned with the growth and metabolism of bone, as well as with the disease processes of the medullary cavity and the osseous structure.

Radio-active phosphorus (P^{32}) has a half-life of 14.3 days and emits beta rays which have a peak intensity of 1.69 m. e. v. Present studies with radio-active phosphorus indicate that the initial uptake of phosphorus is highest in the liver and that approximately 75 per cent. of body phosphate is stored in the bones and teeth. Of the body phosphate, 80 per cent. is deposited as a stable portion of the bones and teeth, and 20 per cent. as a labile portion which is in dynamic equilibrium with the phosphate of the blood plasma. This exchange seems to take place by surface absorption and comes to equilibrium in about two hours after intravenous injection, as shown by the use of radio-active phosphorus (P^{32}). In rachitic rats, vitamin D favors the deposition of absorbed phosphate in the bones, as against the soft tissues, and partially inhibits the re-excretion of phosphate in the intestine. A single dose of vitamin D exerts its maximum effect on the uptake of radio-active phosphorus (P^{32}) in rachitic bone in from fifty-four to seventy-two hours. Experimental work with radio-active phosphorus in animals has shown that the growing epiphyses of bones turn over phosphorus in a ratio of four to one, as compared with the shafts of the bones. In phosphorus deficiency, there is a shift of phosphorus concentration from bone to the soft parts. At the same time, there is a decrease in urinary phosphorus excretion and a corresponding calciuria. Where calcium deficiency obtains, less phosphorus is deposited in the bone and a larger amount is excreted in the urine.

The teeth utilize and exchange, through the pulp and the dentine, a relatively low amount of phosphorus under normal conditions. Very little phosphorus is picked up through the intact enamel unless there are areas of tooth decay.

Kenney, Marinelli, and Woodward, in studying the uptake of radio-active phosphorus (P^{32}) by breast carcinoma, osteogenic sarcoma, and lymphosarcoma, found that osteogenic sarcoma concentrated radio-active phosphorus (P^{32}) more effectively than did normal bone, but that the amount which was concentrated

did not deliver sufficient radiation to destroy the tumor. They also found that primary breast cancer concentrated radio-active phosphorus (P^{32}) to a lesser extent than did the metastatic lymph nodes or even normal lymph nodes in the same patient. Lymph nodes involved by lymphosarcoma showed a selective concentration of phosphorus.

It would appear that the uptake and retention of phosphorus is definitely related to the phosphorus present in the tissues and to the relative rate of metabolism of phosphorus within the tissues. It, therefore, holds that neoplastic tissues with a high rate of mitotic division will utilize increased amounts of phosphorus. This is readily confirmed by studies with radio-active phosphorus (P^{32}).

Erf, Lawrence, Tuttle, and Scott and their associates and Low-Beer and his associates report tracer studies with radio-active phosphorus which indicate that the element is rapidly utilized by red blood cells and lymphocytes in normal persons and in patients with leukaemia and polycythaemia rubra vera. In the first twenty-four hours following tracer radio-active phosphorus (P^{32}) absorption, the erythrocytes contain more phosphorus than the leukocytes. Within forty-eight hours, there is a decline in the amount of radio-active phosphorus contained in the red blood cells of both normal persons and patients with leukaemia or polycythaemia rubra vera. In patients with leukaemia, however, more radio-active phosphorus (P^{32}) is found in the whole blood than in the blood of normal subjects or patients suffering with polycythaemia rubra vera. Patients with leukaemia show an increasing uptake of radio-active phosphorus (P^{32}) absorption by leukocytes. Ultimately, these patients reveal a concentration of radio-active phosphorus (P^{32}) in the leukocytes five times greater than in the erythrocytes present. The plasma concentration of radio-active phosphorus (P^{32}) is similar in normal subjects and in patients with leukaemia and polycythaemia. Under the same circumstances of time and administration, the bone marrow shows a higher concentration of radio-active phosphorus (P^{32}) than does the peripheral blood. In patients with leukaemia, the myelocytes and lymphocytes differ in their proclivities for the uptake of radio-active phosphorus (P^{32}). The nuclei of myelocytes concentrate larger amounts of radio-active phosphorus (P^{32}) than the cytoplasm, while lymphocytes seem to concentrate the same amount in both the nucleus and cytoplasm. The permeation of red blood cells by inorganic phosphorus appears to be a link in the dynamics of cell metabolism, rather than simple diffusion. Body temperature, hemolysis, and certain drugs affect the transfer rate of phosphorus from plasma to red blood cells and reflect changes in cell-membrane permeability.

Radio-active phosphorus has been used extensively in metabolic studies other than those mentioned. Those of diagnostic importance include the use of radio-active phosphorus (P^{32}) in the localization of brain tumors. Because of the short effective range of the beta radiation emitted by radio-active phosphorus (P^{32}), Selverstone, Solomon, and Sweet found that it was necessary to devise a miniature Geiger-Müller counter which could be inserted directly into the brain tissue. Good differentials were obtained between normal and pathological areas, and the method promises to become a part of the neurosurgeon's diagnostic armamentarium.

Clinical studies on the uptake of tracer doses of radio-active phosphorus (P^{32}) by tumors of the breast have yielded some interesting observations. McCorkle, Low-Beer, and their associates have found that malignant tumors of the breast and related metastatic deposits show an increased absorption of radio-active phosphorus; inflammations of the breast also show an increase in the absorption of radio-active phosphorus. This is of some diagnostic significance if the cancer or inflammation is not situated deeper than 0.5 centimeter from the surface.

Radio-active phosphorus has been effectively used in the study of peripheral vascular disease. Friedell, Schaffner, and their associates studied 100 patients in the Cook County Hospital. They found that radio-active phosphorus (P^{32}) was concentrated more rapidly in the tissues of the extremities of older patients with arteriosclerosis than it was in the tissues of younger subjects and those with apparently normal circulation. From this they postulated that the radio-active ion diffused more rapidly into the tissues of older patients and of patients with abnormal circulation. The authors feel that they have established the presence of vasodilation in the capillary bed in patients with arteriosclerosis and in all persons in whom arterio-elasticity has diminished.

Woodward and Kenney have studied the relationship of phosphatase activity in bone tumors to the deposition of radio-active phosphorus. Some bone tumors were found to contain little or no alkaline phosphatase and were found apparently to lack the capacity to lay down calcium phosphate. The majority of osteogenic sarcomata, however, contained large amounts of alkaline phosphatase. It appeared that the more rapid the growth and the greater the osteoplastic tendency, the higher the alkaline phosphatase activity present. Many of the metastases from such tumors contained large amounts of phosphatase. The presence of great phosphatase activity suggested that larger amounts of radio-active phosphorus (P^{32}) would be picked up by both the primary lesion and the metastases. Such proved to be the case. In some osteogenic sarcomata, however, with high phosphatase activity, unknown factors were present which prevented the deposition of calcium phosphate. It was pointed out that this fact not only denoted a poor prognosis but also that this peculiar lack of calcium-phosphate deposition would prevent the possible use of radio-active phosphorus in the treatment of such bone tumors.

Radio-active phosphorus alone has not proved successful in the treatment of primary bone tumors, although its supplementary use with other forms of irradiation has been suggested.

Radio-active phosphorus at the present time is principally used in the treatment of polycythaemia rubra vera, in which it has proved an effective method of temporarily controlling this disease to the extent that some patients live out a normal life expectancy. Each patient requires individual treatment and many require phlebotomy in addition to the radio-isotopic therapy.

Radio-active phosphorus is also used in treating chronic myelogenous leukaemia and chronic lymphatic leukaemia. There is apparently no advantage, by measured life expectancy, in using this therapy over other established methods of treating these diseases. In fact, the consensus is that chronic lymphatic leukaemia responds better to external roentgen irradiation than to radio-active phosphorus. In the acute forms of leukaemia, radio-active phosphorus is contra-indicated.

There have been indifferent results in treating multiple myeloma, Hodgkin's disease, lymphosarcoma, and metastatic carcinoma of the breast with radio-active phosphorus. An occasional case will show temporary relief from pain and regression of tumor with improvement of general well-being for a brief period of time. Rarely is re-ossification noted.

Other Radio-Active Isotopes with Bone Selectivity

Of some practical importance to the orthopaedic surgeon are certain radio-isotopes of calcium, strontium, and gallium.

Radio-Active Calcium (Ca^{45})

Radio-active calcium (Ca^{45}) has beta emissions with peak intensities of 0.19 m. e. v. (95 per cent.) and 0.91 m. e. v., which make this isotope difficult to use in tracer studies. The low intensity of the emanations, together with its wide concentration in bone, detracts from the usefulness of radio-active calcium as a therapeutic agent. Furthermore, although a product of the *n*, *p* reaction * in the pile and also of the cyclotron, radio-active calcium (Ca^{45}) is limited in supply. It has a relatively long half-life of 180 days, bespeaking a hazard for personnel and in clinical use. Ashing of all biological material for proper radio-isotopic assay is necessary in animal experimentation with radio-active calcium.

Radio-Active Strontium (Sr^{89})

Radio-active strontium, an alkaline earth metal, is a chemical analogue of calcium and is readily available. Strontium (Sr^{89}) has a half-life of fifty-five days and emits beta rays with an energy maximum of 1.52 m. e. v. It is thus more easily detected than calcium (Ca^{45}) and has been found more suitable for biological investigations. There is, however, a biochemical difference between the two elements; while strontium is capable of replacing calcium to a considerable extent in the bones, Shipley and his associates have pointed out that this mineral cannot replace calcium in the formation of normal bone. It seems necessary, therefore, to evaluate both calcium (Ca^{45}) and strontium (Sr^{89}) in tracer studies of bone, utilizing the combined results to further unravel the mysteries of bone metabolism.

Pecher has been able to show quantitatively the exchange of calcium and strontium in mice. After twenty-four hours, 58 per cent. of a dose of radio-active calcium (Ca^{45}) was recovered in the skeletons of mice (average of thirty mice), while 33 per cent. of radio-active strontium (Sr^{89}) was recovered from the skeletons of mice (average of thirty-five mice). It appeared that the uptake from both radio-isotopes was greatest at the end of eight hours following intravenous administration. The uptake of radio-active calcium and strontium was nearly three times greater following intravenous administration than after oral administration. Both calcium and strontium, previously fixed in the skeletons of mice, migrated to the foetus in the last days of pregnancy. Studies have also shown that these isotopes can be transferred to the offspring through the milk. Radio-active strontium, administered intravenously into two lactating cows, was recovered in the milk at the rate of 10 per cent. of the total dose in the first four and one-half days after its administration.

Marshak and Byron, using phosphorus (P^{32}) and strontium (Sr^{89}) in studying healing bone in rats which had had surgically produced bone injuries, compared the uptake of the two radio-active substances. In young animals, the latent period for an increased uptake of phosphorus was shorter than in older animals (two as compared with four days). The maximum uptake of phosphorus and strontium was found to occur in eight to ten days in young rats, as compared with a maximum of fifteen days in older rats. This paralleled the gross healing of the old and young bones. By comparing the ratio of uptake of these two radio-active metals, it was found that the ratio tended to increase in the latter part of the healing process. It was pointed out that this fact might make it possible to utilize such a study to differentiate between proliferating and calcifying stages of bone healing.

* The abbreviation "*n*, *p* reaction" refers to the term "neutron, proton reaction". In discussing nuclear reactions, they are referred to in terms of the in-going particle and "quantum" or both and the out-going particle and "quantum" or both. The *n*, *p* reaction occurs in the atomic pile, among many other nuclear reactions, and in the cyclotron. This reaction, while rare in the pile, gives rise to transmutation and hence to certain carrier-free materials.

Isolated studies have been made on bone disease by Low-Beer and his associates, which include bone atrophy and rickets. The study of a late case of rickets indicated that the primary defect in that disease was not in the absorption of the bone salts but in the failure of the ossification mechanism.

In studies on the distribution of radio-active calcium (Ca^{45}) within the skeleton, it has been found that calcium (Ca^{45}) is present in higher concentrations in cancellous bone than in cortical bone. More calcium (Ca^{45}) has been found in the epiphysis than in the diaphysis; and in growing animals, the concentration is particularly high at the epiphyseal plate. Experimental fractures, after the administration of calcium (Ca^{45}), have shown a higher concentration of calcium (Ca^{45}) about the healing callus and bone than that found in control bones.

Studies have been made on rickets, using as tracers radio-active phosphorus (P^{32}), calcium (Ca^{45}) and strontium (Sr^{89}). These studies show no inability on the part of the rachitic animal to absorb the phosphate. Absorption of labeled strontium, on oral administration in similar experiments, is practically doubled, as is calcium (Ca^{45}) when vitamin D is given. These studies indicate that vitamin D aids both in the absorption of calcium from the gastro-intestinal tract and in the deposition of calcium and strontium in the bone. When radio-active calcium is administered to pregnant mice, the maximum uptake is in the skeleton. The relative uptake in the soft parts is low. In the last few days of pregnancy, calcium is transferred to the foetus, and new-born mice may have in their bodies three times as much radio-active calcium as that remaining in the mother's skeleton. Likewise, non-radio-active offspring nursed by mothers which have received radio-active calcium rapidly show evidence of becoming radio-active through the milk.

The group at Georgetown University Medical Center Radio-Isotope Laboratory have been working on some general problems related to the dynamics of calcium metabolism, the processes of normal and abnormal bone formation and resorption *in vivo*. They have advanced this study by the development and application of two new tools:

1. The first of these tools is a powerful synthetic group of calcium-complexing agents in the form of unnatural, non-metabolized amino-acids. By the administration of these powerful agents, it has been found possible to regulate experimentally and to maintain systemic ionic calcium levels in suitable experimental animals and in man. Administration of such a complexing agent, as, for example, ethylene-diamine-tetra-acetate, results in the formation of a soluble, non-ionized calcium complex *in vivo*. This removes the calcium ion from its usual sphere of metabolic activity. By this method, controlled studies have been initiated on the biological functions of the calcium ion in coagulation processes, in bone formation and resorption, and in the control of parathyroid function. One of the early findings in this work has been the demonstration of dystrophic calcification under conditions of systemic hypocalcaemia, resulting in the deposition of calcium in soft-part tissues and in the kidney.

2. In combination with the experimental calcium-controlling device, there has been utilized radio-active calcium (Ca^{45}) as a tracer element to label exogenous calcium. The tool, radio-active calcium, was used in order to trace its movement through the body in normal circumstances and under conditions of ionic deprivation. It has been found that intravenously injected radio-active calcium leaves the blood in an extraordinarily rapid manner and under the control of apparently four independent physiological processes. The nature of these processes is now under examination.

Utilizing the techniques described above, it can be demonstrated that the total blood calcium exchanges with the extravascular system calcium available to the extent of 65 per cent. per minute. Under systemic hypocalcaemic conditions, induced by the administration of complexing agents, three of the physiological controlling processes seem to remain the same. The fourth process, however, which is believed to represent that of urinary calcium excretion, is increased. This effect may be an indirect one, brought about by the initial effect of hypocalcaemia which stimulates parathyroid function, resulting in phosphaturia and concomitant calcium excretion. Extension of these studies to bone function is now under way.

Attempts have been made to use calcium (Ca^{45}) in the treatment of malignant bone tumors. This material, lacking in specific tumor concentration potential, is also of insufficient intensity to control effectively bone sarcomata which are, in general, highly radio-resistant.

Demonstration of the selective localization of strontium in bone has strongly recommended its use for trial therapeutic irradiation in bone. Pecher in 1941 reported clinical and postmortem studies with radio-active strontium on a group of patients with carcinoma, having definite bone metastases. The patients were given total doses of only one to two millicuries of strontium (Sr^{89}) because of the relatively long half-life (55 days) and the attendant danger of delayed radiation effects. Such dosage was found to be sublethal, and, in later studies, doses up to 10 millicuries were administered without undue damaging effects at the end of six months.

Treadwell, Low-Beer, Friedell, and Lawrence, in 1942, after investigation of the uptake of radio-active strontium by bone tumors concluded that strontium (Sr^{89}) was not practical as a primary therapeutic agent in bone tumors. The uptake in both the surrounding marrow, bone, and muscle was definitely a limiting factor in dosage and prevented the therapeutic agent from affecting the tumor adequately.

Friedell, Thomas, and Krohmer have used radio-active strontium (Sr^{90}), with a half-life of twenty-five years and with beta-ray emissions of 0.65 m. e. v., in applicators for the treatment of certain diseases of the

eye. They pointed out that the average m. e. v. is about 0.195, but that a daughter product, yttrium (Y^{90}), has a half-life of 62 hours and has beta-ray emissions with a maximum of 2.2 m. e. v. and an average energy of 0.8 m. e. v. Thus, the application of Sr^{90}, with its daughter product, compares favorably with the effects of beta-ray irradiation from radon. Treatment from this source can be used for corneal ulcers, vernal conjunctivitis, and superficial tumors. Treatment from this source is made by surface application.

Radio-Active Gallium (Ga^{72})

The studies of Dudley and his colleagues on the physiological characteristics of gallium have shown that this element is an avid bone-seeker, and have created considerable interest in the possibility that a new tool for the study of bone metabolism has been found. More recent studies have indicated that it may be used as a diagnostic method and deserves investigation as a method of therapy in bone tumors.

Gallium (Ga^{72}) has a half-life of 14.1 hours, and emits negative beta rays, with a maximum energy of 3.4 m. e. v., and gamma rays with a maximum energy of 2.5 m. e. v. Extensive studies have been made by Dudley and his co-workers on the toxic effects of stable gallium to provide a basis for evaluating the effects of carrier gallium when radio-active isotopes of this element are administered. These investigators have found that gallium citrate is more suitable as a means of administering soluble gallium to experimental animals than is gallium lactate. It is not absorbed from the gastro-intestinal tract, and it produces no significant effect when fed to rats over a period of weeks. The toxicity (LD^{50}, 10 days) of gallium citrate on a basis of one milligram of gallium per kilogram of body weight for dogs and goats was 10 to 15 milligrams per kilogram of weight. Toxic doses of gallium citrate in the rabbit resulted in marked kidney changes with an uncompensated acidosis and insignificant changes in the serum sodium and potassium levels.

Properly controlled gallium citrate offers a satisfactory medium for the administration of soluble gallium and gives rapid localization of this substance in osteoid structures. Studies of the distribution of the gallium citrate in the rat, rabbit, and dog indicate that only the bone and kidneys received large amounts of the element. The other soft tissues received no significant concentration. A series of animals injected with from 0.9 to 1.1 millicuries of gallium citrate (Ga^{72}) per kilogram showed that 44.6 per cent. of the injected dose was excreted in the urine in sixteen hours after injection, while 40.2 per cent. was deposited in the bone. In general, the greater the quantity of gallium excreted, the less is deposited in the bone. The greatest disadvantage to the use of gallium citrate (Ga^{72}), when employed for tracer studies or in therapeutic amounts, is the possible radiation injury produced in the kidneys, as the radio-isotope is concentrated and excreted by these organs. In addition, stable gallium compounds at toxic levels produce renal changes.

Dudley and his associates have shown that radio-active gallium in young rabbits is found principally at the epiphyseal junctions of the long bones in eight hours. This is the region of greatest osteogenic activity. In older animals, the trabecular bone showed the greatest activity, while the peridontal tissues of both age groups exhibited an especial affinity for the injected gallium. A dog, weighing 8 kilograms, which was found to have a spontaneous osteoclastic lesion of the foreleg, was given a single subcutaneous injection of 0.5 millicuries of gallium lactate (Ga^{72}) per kilogram of body weight. In twenty-four to forty-eight hours, Geiger-counter readings indicated 33 to 39 per cent. higher radio-activity over the osteoid lesion than over the same area on the opposite normal leg. There were no hematological changes noted in a period of forty-five days.

Mulry and Dudley, in clinical studies at the Bethesda Naval Hospital, found that there was a differential radio-activity of gallium (Ga^{72}) in bones as compared with surrounding soft parts. These investigators used Geiger-counting techniques applied to the skin surface for the localization of radio-active gallium (Ga^{72}) in bone. They found that intravenous tracer doses of gallium (Ga^{72}) were selectively concentrated in both osteogenic and osteolytic bone lesions in fifteen of eighteen patients with primary and malignant metastatic bone tumors. Early metastases to bone were identified before changes were apparent by roentgenogram.

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HARRY B. MACEY

1905–1951

Dr. Harry B. Macey of Temple, Texas, died on Sunday, August 5, 1951, at his farm near Temple, bringing to an untimely close the career of a man well recognized throughout this country for his accomplishments in, and contributions to, orthopaedic surgery.

Dr. Macey was born July 9, 1905, at Lebanon, Tennessee, received the degree of B.A. in 1926 from Cumberland University, Lebanon, and the M.D. in 1930 from the University of Tennessee, Memphis. He served an internship at the New York Polyclinic Hospital from October 1930 to July 1932. He was associated with the Campbell Clinic in Memphis from July 1932 to 1933. He entered the Mayo Foundation as a Fellow in Orthopaedic Surgery in January 1934, and became a member of the permanent staff of the Mayo Clinic on January 1, 1936. He was certified by the American Board of Orthopaedic Surgery in 1937 and became a member of The American Orthopaedic Association in 1946.

Besides membership in The American Orthopaedic Association, he held membership in the American Medical Association, The American Academy of Orthopaedic Surgeons, the Central Surgical Association, the Clinical Orthopaedic Society, the Southeastern Surgical Congress, the Alumni Association of the Mayo Foundation, the Sigma Alpha Epsilon academic fraternity, and the Phi Chi medical fraternity.

Dr. Macey entered the Medical Corps of the United States Navy in 1941. He served at the United States Naval Hospital at Corona, California, until stricken with coronary embolism in 1943; he was separated from the Naval medical service in 1946. He then joined the staff at the Scott-White Clinic in Temple, Texas, to head the Orthopaedic Service there.

Dr. Macey was a hard worker, a thorough believer in the future of orthopaedic surgery, making many contributions to advancement in the field. No problem was too difficult for him to undertake with a real intent to accomplish some good for the patient. A skillful operator, his efforts helped many patients to recovery from troublesome conditions which had not responded to treatment.

Dr. Macey was widely known and very popular among those who were acquainted with him. Those who knew him best feel not only that they have lost a real friend, but that orthopaedic surgery has suffered a great deprivation.

News Notes

The Seventh Annual Meeting of the **American Society for Surgery of the Hand** will be held at the Palmer House, Chicago, Illinois, January 25 and 26, 1952.

The Nineteenth Annual Meeting of **The American Academy of Orthopaedic Surgeons** will be held at the Palmer House, Chicago, Illinois, January 26 to 31, 1952.

Applications for the 1952 Part I examinations of **The American Board of Orthopaedic Surgery,** should be made before November 30, 1951, to Harold A. Sofield, M.D., Secretary, 122 South Michigan Avenue, Chicago 3, Illinois.

The Arkansas orthopaedic surgeons organized the **Arkansas Orthopaedic Society** in Little Rock on July 7, 1951. The following officers were elected:

President: F. Walter Carruthers, M.D.
Vice-President: W. E. Knight, M.D.
Secretary and *Treasurer:* Kenneth G. Jones, M.D.

The next meeting will be held October 29, 1951, at Little Rock.

The Thirty-seventh Clinical Congress of the **American College of Surgeons** will be held at San Francisco, California, November 5 to 9. Dr. Henry W. Cave of New York is President of the College. Of special interest is the Forum on Fundamental Surgical Problems, designed to bring out the best of what is new in surgery and to give younger surgeons doing original work a chance to be heard. The Forum begins on Monday afternoon, November 5, and continues through Friday, November 9, with twelve sessions in all. Dr. Owen H. Wangensteen, Professor of Surgery, University of Minnesota Medical School, is Forum chairman.

The **New Jersey Orthopaedic Society** offers an award of $100 for the best paper written on an orthopaedic or a closely related subject by a resident or intern in the State of New Jersey. The paper selected will be read by the author at the Spring Meeting of the New Jersey Orthopaedic Society in 1952.

Papers must be submitted to the Secretary of the New Jersey Orthopaedic Society, Dr. Philip Willner, 852 South 11th Street, Newark 8, New Jersey, on or before January 15, 1952.

The Coordinating Council for Cerebral Palsy in New York City, Inc. will sponsor again this year a two-week Cerebral Palsy Institute, to be given from January 21 through February 1, 1952. Qualified physicians, physical, occupational, and speech therapists, nurses, social service, rehabilitation and guidance workers, teachers, and psychologists are eligible. The Institute will include seminars, field trips, clinical demonstrations, and lectures. Emphasis will be placed upon the medical, socio-psychological aspects of mental subnormalities of the cerebral palsied and on the recent contributions of psychometrics to this field.

Following the Institute, and starting on February 4, 1952, The Coordinating Council for Cerebral Palsy in New York City, Inc., in cooperation with the College of Physicians and Surgeons, Columbia University, will offer a three-month post-graduate cerebral-palsy course for qualified physicians, occupational therapists, and physical therapists.

Full information and application blanks can be obtained from Miss Marguerite Abbott, Executive Director, The Coordinating Council for Cerebral Palsy in New York City, Inc., 270 Park Avenue, New York 17, N. Y.

The American Academy for Cerebral Palsy announces that its Annual Meeting will be held in Boston, Massachusetts, at the Copley Plaza Hotel, on Friday and Saturday, November 16 and 17, 1951. The Friday afternoon scientific session will be an open meeting and all physicians interested in the problem of cerebral palsy are cordially invited to attend. The program will include:

The Cerebral Palsy Problem in 1951: Bronson Crothers, M.D., President.
Physiology of Motor Learning as Applied to Cerebral Palsy: Frances Hellebrandt, M.D.
Studies of Gait Patterns of the Hemiplegic Patient: Morton Marks, M.D.
Surgical Methods for Functional Improvement of the Hand in Spastic Paralysis: William Cooper, M.D.
Diastematomyelia: Franc Ingraham, M.D.
Paradoxical Benefit of Cortical Ablation for Selected Hemiplegics: Wilder Penfield, M.D.

How parents of cerebral-palsied children can effectively come together to exchange experiences, secure information, and participate in developing services for cerebral-palsied children is outlined in the new *Parents' Study Guide*, published by the **National Society for Crippled Children and Adults.**

Copies may be ordered from the National Society for Crippled Children and Adults, 11 South LaSalle Street, Chicago 3, Illinois.

INTERNATIONAL SOCIETY OF ORTHOPAEDIC AND TRAUMATIC SURGERY

The Fifth Congress of the **International Society of Orthopaedic and Traumatic Surgery** was held in Stockholm from May 21 to 25, 1951. Over 300 orthopaedic surgeons from all over the world were present. The meetings were held in Stockholm's beautiful concert hall. The opening session was attended by the King; the Queen unfortunately was ill. Prof. Henning Waldenström (Sweden), Honorary President of the Congress Committee, traced the development of orthopaedics, pointing out the present universal trend toward a biological approach.

Sir Harry Platt, President of the Society, presided over the meetings. The sessions were beautifully organized and much credit is due the Committee for the efficient manner in which the meetings were conducted. English and French were the official languages.

There were two main subjects: (1) Low-Back Pain and Sciatica; (2) Avitaminosis and Osteopathy. A total of eighty-five scheduled papers on these and many other topics were read by numerous contributors. Some of the speakers did not appear but, with the unscheduled talks, the total number came close to eighty during the five-day period.

Low-Back Pain and Sciatica

1. *Papers on Surgical Treatment and Results*

Dr. J. S. Barr (U. S. A.) reviewed the problem of low-back and sciatic pain, emphasizing its many ramifications and presenting a summary of the etiology, anatomical considerations, and pathology. Emphasis was placed on the poorly understood psychological aspects of low-back pain. Treatment, both conservative and operative, was discussed. An end-result study of 100 cases operated on at the Massachusetts General Hospital during the period 1941 to 1946 was reported. At operation all patients were proved to have a ruptured intervertebral disc. Of these, fifty were treated by disc excision alone and fifty by fusion after excision in a combined procedure. The two groups were comparable as to age, sex, and location of lesions. Of the cases with excision, 56 per cent. had no sciatic symptoms and in 42 per cent. these symptoms were mild, whereas of the group with excision and fusion 68 per cent. had no symptoms and 28 per cent. had mild sciatic symptoms. Back symptoms, on the other hand, were found as follows: in the cases with excision, none in 22 per cent. and mild symptoms in 42 per cent.; in the cases with excision and fusion, none in 58 per cent. and mild in 22 per cent. There was thus a considerable difference between the two groups in regard to complete freedom from back symptoms—58 per cent. as compared with 22 per cent. Including mild symptoms, the results of fusion were satisfactory in 80 per cent. of cases as compared with 64 per cent. in the excision group. X-ray studies, including bending films, were not carried out in all cases. Of the twenty-seven cases known to have solid fusion, 74 per cent. had no symptoms and 22 per cent. had only mild symptoms.*

Mr. R. H. Young reported a study of 957 patients operated on for back pain. Excluding forty-four cases of spondylolisthesis, there were 913. He expressed the opinion that, in most instances, lame back and sciatic pain are due to lesions of the intervertebral discs, that nearly all other orthopaedic causes of backache are revealed by x-ray, and that the remaining cases are due to visceral disease or neurosis. He favored a conservative approach to treatment, using rest and a corset or body cast, but he discounted the value of other time-honored procedures such as manipulation, physical therapy, and exercises. In the 913 cases with operative treatment in this series, the following findings were recorded: protrusion, 750 cases; disc lesions without protrusions, eighty-two; osteo-arthritis causing root irritation, twenty-two; abscess, three; tumors, two;

* Dr. Barr's paper has been published in *The Journal* (Vol. 33-A, No. 3, 633–649, July 1951).

peridural adhesions, twelve; negative exploration, forty-two. Multiple disc protrusions were found in 12 per cent. The disc lesions other than protrusion included (1) a bulging, springy annulus with a degenerated and fragmented disc; (2) a soft area in the disc; (3) a "scarred disc", meaning a narrowed inelastic disc to which the nerve is often adherent. In osteo-arthritis, nerve-root pressure was found to be due to postero-lateral lipping. Chiseling off this lipping relieved pain. Simple laminectomy or facetectomy had not been successful in the speaker's hands. The correlation between signs and symptoms and the location of protrusion both with regard to the interspace and the position relative to the nerve root was discussed. There were forty-two patients with negative explorations who continued to have typical attacks. Of these, four cases were severe enough to require re-exploration when a disc was found. In the follow-up examination, 616 patients with proved disc protrusion and sixty with a degenerated disc were studied. The author feels that the age of the patient and the duration of symptoms do not affect the prognosis. More or less severe recurrences were found in 133 patients. Of these eighteen were re-explored and further protrusion was found, while two were operated on for a second recurrence. Recurrence occurred at another disc rather than at the same interspace in the proportion of two to one. Recurrence at the same disc usually followed inadequate removal, frequently due to the disc being "unripe" or not sufficiently degenerated to permit removal. Pain was unrelieved by operation in forty-four cases. Re-exploration in twenty-two of these showed a further protrusion in nine, six of these being at another level. The remaining thirteen all had dense perineural and peridural adhesions binding the root to the mobile posterior part of the canal. In the cases in which disc lesions without protrusion were found, the results were only about half as good as in those with protrusion. In the fifty cases with back pain alone, thirty-one protrusions were found and fifteen lesions without protrusion. The indications for spine fusion were considered to be (1) spondylolisthesis, (2) adhesions following removal of a disc, and (3) certain cases of backache. The author did not consider fusion at the time of disc removal to be necessary. The technique of spine fusion included two tibial grafts bolted to the spinous processes, using spring washers to obtain compression and iliac grafts on the laminae. Union grossly and histologically was demonstrated at six weeks.

Dr. Louis Pouyanne (France) reported on the results of surgical treatment. For sciatic pain the indications for operation were considered to be failure of other methods of treatment and violent and recurring pain. His technique included a minimum but adequate laminectomy and nerve-root section in exceptional cases,—as for example, when the disc could not be removed. In the author's opinion, fusion was indicated for displaced vertebrae, limited arthrosis, unsatisfactory disc operations, and old and rebellious lumbar pain. In the heavy laborer it was also considered a wise precaution. About 10 per cent. of the patients required fusion.

Dr. Eduard Güntz described two types of disc lesions: displacement of disc tissue through the annulus or cartilage plates and alteration in the composition and turgor of the nucleus. Low-back pain in his opinion resulted from arthritis of the posterior articulations rather than from nuclear hernia. Some operative failures were believed to be explained by this. In his practice one patient in five was treated surgically, always without laminectomy. Postoperative care included bed rest for three weeks, a plaster jacket for four to six weeks, and a convalescence period of at least three months before return to heavy labor.

Dr. Ragnvald Ingebrigtsen (Norway) reported his results in 180 patients operated on for rupture of an intervertebral disc. Of these, 100 were examined one or more years after the operation with the following results: thirty-nine were cured, twenty-one greatly improved, twenty-nine improved, and eleven were failures. In twenty-one of these, fusion was combined with disc excision. Of the fused cases, sixteen patients were completely relieved, three were working with slight back pain, and two were unable to work. The author's indications for primary spine fusion were spondylolisthesis, narrowing of more than one disc, and retroposition of a vertebra; the operation is also indicated when an inferior articular process had been partially resected at operation.

Dr. Enzo de Marchi (Italy) reported follow-up studies on 207 of 307 patients operated on for prolapsed discs by hemilaminectomy and thorough disc removal without fusion. Results were excellent in 59 per cent., good in 26 per cent., poor in 8.5 per cent., and bad in 6 per cent. In five patients second operations were performed and in each a recurrence or a new protrusion was found.

Drs. Gunnar Wiberg and Folke Ståhl (Sweden) reported the results of surgical treatment of 624 patients for prolapse of a lumbar intervertebral disc. Of these, twenty-seven (4.3 per cent.) had further surgery because of persistence or recurrence of lumbosacral pain. In this latter group the operative findings were: disc prolapse in the explored space, six; disc prolapse in an unexplored space, two; true recurrence with further prolapse of the nucleus, nine; a new prolapse at another space, five; stricture of the nerve root by scar, three; and diffuse disc protrusion, one.

Dr. Carlo Pais (Italy) reported that during the last ten years 1000 patients had been operated on for low-back and sciatic pain at the Istituto Rizzoli. Disc protrusions were found in 906 cases. In the ninety-four cases where no disc protrusion was found, further exploration revealed adhesive arachnoiditis, hypertrophy of the ligamentum flavum, spondylolisthesis, spondylolysis, spina bifida, osteophytes, tuberculous arthritis, intradural tumors; in some cases no pathological conditions were found. The late results showed: 83.33 per cent. relieved, 12.45 per cent. improved, 1.25 per cent. unchanged, 0.22 per cent. aggravated, and in 2.75 per cent. a second operation because of recurrence.

2. *Biophysical and Physiological Investigations on Lumbar Discs*

Dr. Carl Hirsch (Sweden) reported on his anatomical studies of lumbar discs. Degenerative changes were found so frequently they were considered more or less physiological. The initial process was found to be degeneration in the nucleus with changes in the annulus secondarily. No evidence of healing of the disc was found. He described mechanical experiments made with a special apparatus to register the deforming forces, both as to direction and magnitude, in the different parts of the disc when subjected to pressure. In "healthy" discs no variation was found, while in degenerated discs there was considerable variation in the different discs and in different parts of the same disc. The resulting abnormal mechanics of the disc and abnormal movement between vertebrae was described. Rotatory and sliding movements were noted. In studies of disc puncture, only a fraction of a cubic centimeter could be injected into a healthy disc while a degenerated one would accommodate 1 to 2 cubic centimeters. Raising the intradiscal pressure would reproduce the patient's pain in cases of lumbago. Evidence was presented to support the view that lumbago is the result of a functional disturbance in one or more discs producing irritation of the sensory endings in the long ligaments.

Dr. Bengt Sylvén reported on electromiscroscopic studies of the normal nucleus pulposus in man and in young calves. By fractionation procedures the matrix was found to consist of collagen fibrils, a polysaccharide, a protein component attached to the polysaccharide, and water. These elements formed a three-dimensional lattice gel system with a water content of 83 per cent. The polysaccharide appeared to be chondroitin sulphuric acid rather than hyaluronic acid as previously thought. These polysaccharides are presumed to be chemically linked to the surface of collagen fibrils, rendering them hydrophilic by virtue of their polar (—OH) groups. Diffusion studies revealed that simple diffusion cannot fulfill the nutritional requirements and some other transport mechanism must exist. Degenerative changes were found to appear in the third decade. A gradual decrease in the number of chondrocyte-like cells occurred, associated with a patchy loss of mucoid material. Large collagen bundles without mucoid appeared. It was felt that these changes implied marked alterations in the gel lattice.

Dr. Sten Paulsson (Sweden) described new optical methods of quantitative diffusion studies on mesenchymal tissues.

Dr. Olle Snellman (Sweden) reported that the diffusion rate of many substances in the nucleus pulposus was low and about the same as that in a gelatin gel of the same water content.

Mr. John Charnley (Great Britain) in a preliminary report on experiments concerning the swelling of the nucleus pulposus in isotonic saline found this phenomenon to be greater in this tissue than in any of the others tested. Although there was marked variation, some discs increased their volume 50 per cent. at the rate of 10 per cent. per hour. The expanding tissue exerted pressures of 100 to 150 millimeters of mercury. The author postulated that acute episodes of the lumbago-sciatica syndrome might result from some as yet unexplained acute swelling due to imbibition of intercellular fluid.

Dr. Bernard Dubois (Switzerland) discussed pathological changes in the lumbar region, considering them as biological rather than mechanical changes, which involved not only the discs but also lateral ligaments, ligamenta flava, and other joint structures.

3. *Diagnostic Studies*

Dr. Folke Knutsson discussed lumbar myelography with a water-soluble 20 per cent. abrodil solution. Some 900 examinations with 8 to 10 cubic centimeters had been performed. The technique was described at some length. The advantages of the method included superior detail with excellent visualization of the root sheaths and the ready absorption of the material so that removal was not necessary. A disadvantage, considered small by the author, was that the material is an irritant, requiring preliminary spinal analgesia with 1 cubic centimeter of 5 per cent. procaine. Complications encountered included nausea, shock, unconsciousness, and epileptiform cramps; these were transitory as a rule.

Dr. J. J. Herbert (France) advocated and illustrated the use of epidural myelography. By careful study of different projections, with the patient standing in flexion and extension, good results had been obtained. He condemned the use of lipiodol intradurally because of sequelae, stressed the importance of clinical diagnosis and of deferring surgical treatment for four to five months after onset of symptoms so that the herniation would be mature. Spine fusion after disc removal was considered to give better results.

Dr. Knut Lindblom described the technique and results of diagnostic disc puncture, made by injecting 2 cubic centimeters of a 35 per cent. diodrast with 0.25 cubic centimeter of 5 per cent. procaine under fluoroscopy, with a double needle. The normal disc takes 0.5 cubic centimeter of fluid, while pathologically involved discs require more. The method made it possible in some cases to demonstrate that the back pain originated in one disc and the sciatica in another. Distention of the normal disc produced local pain, while that of the involved disc reproduced the patient's low-back and sciatic symptoms. Normal and abnormal discograms were shown. There was no evidence that disc protrusion had resulted from the procedure.

Dr. P. Erlacher (Austria) pointed out the advantages of nucleography. These included information as to the shape and situation of the nucleus within the disc, the size of a herniation, and the degree of degeneration of the annulus. He stressed that this method often gave results where myelography failed.

4. *Other Causes of Back Pain*

Dr. R. K. Ghormley (U. S. A.) analyzed the etiology of 2000 cases of backache with and without sciatic pain which were seen at the Mayo Clinic in 1940. Most of the patients were suffering from conditions other than protrusion of an intervertebral disc, such as rheumatoid spondylitis, osteoporosis, neoplastic diseases, and others.

Dr. Steele F. Stewart (Hawaii) reported the results of a study of backache occurring in stevedores who had had pre-employment x-ray examinations. A thin intervertebral disc appeared to be the most consistent x-ray finding which subsequently was associated with backache. In cases of spondylolisthesis, the incidence of backache increased two-fold after this heavy work. Spondylolysis and spina bifida were not associated with any increased incidence, while asymmetrical facets were associated with a very slight increase.

Drs. Jean Delchef and N. Walch (Belgium) in a study of unsuccessful operations for lumbar and sciatic pain came to the conclusion that spinal arthrosis and other causes, rather than intervertebral-disc lesions, are responsible for this syndrome. Gross congenital anomalies were considered of importance.

Drs. J. E. Samson (Canada) and Carlo Marino-Zuco (Italy) came to similar conclusions.

5. *Reports on Operative Technique*

Dr. Pierre Truchet reported on the use of a Wilson spine plate combined with a bone graft bolted to the sides of the spinous processes.

Dr. Robert Judet reported on the use of an acrylic prosthesis which bound the last three lumbar vertebrae to the posterior superior iliac spines. By means of this, early mobilization was possible.

Avitaminosis and Osteopathy

Dr. Raffaele Zanoli (Italy) gave an exhaustive review of the subject. Vitamin A has been shown to influence bone growth, affecting enchondral ossification and bone repair. He cast grave doubt on the part played by vitamin-A deficiency in the osteochondrodystrophies, a view at variance with some workers. Hypervitaminosis A in children produces mid-diaphyseal ossification of long bones, whereas experimentally with larger doses cortical thinning and fractures result. Vitamin-B complex also influences growth. This is most marked in deficiencies of B_1. Nicotinic acid has been shown to stimulate and accelerate the formation of fracture callus. Subclinical deficiency of riboflavin during early pregnancy results in various skeletal deformities in the offspring. Pantothenic acid and biotin deficiencies have also been responsible for deformities. An excess of vitamin B has been shown to arrest osteoblastic activity and collagen formation. In the case of vitamin-C deficiency, acute lack produces scurvy, while a chronic deficiency produces osteophytes and arthropathies resembling chronic rheumatic joint disease. The author feels that vitamin C definitely affects callus formation in fractures, but most investigators feel it does not accelerate this process unless a deficiency had previously existed. Vitamin D is considered by the author not only to prevent rickets and osteomalacia but also to play a part in senile osteoporosis and in osteodystrophy. An excess of vitamin D causes decalcification and fractures. Vitamin E may possibly be concerned with the concentric atrophy of bone which is seen in certain muscular diseases.

Dr. E. Kodicek (Great Britain) and his collaborators reported on the effects of chronic partial deficiency of vitamin C in guinea pigs. In addition to the known changes of scurvy, slow healing of fractures was noted. In partial deficiency, hyperostotic changes with an "outward-radiating trabecular pattern" were found beneath the periosteum. Joint changes presenting a histological picture like human rheumatoid arthritis were also frequently seen. Cortisone was found to relieve the joint swelling. In studies on wound healing, it was found that normally much alkaline phosphatase is present when collagen formation is at its peak. In vitamin-C deficient animals, on the other hand, no alkaline phosphatase was found in the wounds. The arrangement of collagen fibers was also affected. In "normal" wounds they were arranged parallel to the surface in an orderly fashion; whereas in "scorbutic" wounds the arrangement was irregular and the fibers were ensheathed in a mucopolysaccharide. Vitamin C appears to have a profound influence on mucopolysaccharide metabolism.

Dr. Guiseppe Annovazzi (Italy) gave a progress report on his experiments on the influence of vitamin C on formol-induced arthritis in guinea pigs. The arthritis was most severe if the vitamin-C deficiency was started soon after the arthritis was produced and least severe where avitaminosis C had already been established when the experimental arthritis was induced. Further studies on the use of large doses of vitamin C in the treatment of the established arthritis and other aspects of the problem are in progress.

Dr. Calogero Casuccio (Italy) and collaborators produced evidence that vitamin-E deficiency delayed callus formation in experimental fractures, and that hypervitaminosis E increased the percentage of weight gain in young rats, while deficiency of the vitamin decreased it. Histological modifications of cartilage growth were noted in the animals with these deficiencies.

Dr. A. R. Shands (U. S. A.) reported on the present incidence of bone lesions associated with vitamin deficiencies in fourteen children's hospitals in the United States. Among 176,220 admissions, there were one case of hypervitaminosis A, forty-eight cases of scurvy, sixty-one of acute rickets, and 1,213 of healed rickets. Several unusual cases were also reported.

Congenital Dislocation of the Hip

Dr. E. Severin (Sweden) reported on the growth and development of congenitally dislocated hips treated by closed reduction and studied by arthrograms and follow-up examinations over a prolonged period. Soft-tissue interposition between the femoral head and the pelvis was found in the majority of cases. This usually atrophied if reduction was maintained. Soft-tissue interposition was not considered an indication for open reduction. This operation should be reserved for the very few cases in which closed reduction fails.

Dr. Eivind Platou (Norway) considered anteversion of the femoral neck as the chief cause of failure after closed reduction. He advocated derotation osteotomy as part of the primary treatment in almost all cases where anteversion was 45 degrees or more. A subtrochanteric osteotomy fixed with a plate and screws was used.

Dr. André Trèves (France) described a modification of the treatment of congenital dislocation of the hip by the method of Le Damany. After a three-month period of plaster fixation, the patient was placed in an appliance permitting hip flexion and knee motion, but preventing extension and adduction of the hip. This was thought to favor deepening of the acetabulum and derotation of the femoral head.

Dr. Jean Judet (France) reported on the technique of treatment of old unreduced dislocations of the hip and the results in adults fitted with an acrylic prosthesis. By lengthing the muscles, it had been possible in all the forty cases reported to lower the head without shortening the femur. The old acetabulum was used unless the head was dislocated upward more than six centimeters. In that case a new acetabulum was made at the higher level. The results were satisfactory as regards function and relief of pain.

Dr. Ferdo Grospič (Yugoslavia) showed a movie of three cases in which the hip was exposed by a curved lateral incision, the acetabulum reamed out, and the femur shortened by resection of a segment; this was followed by fixation with a Küntscher rod and insertion of the femoral head into the deepened acetabulum. Immobilization in plaster was maintained for three weeks. Results were excellent.

Other Hip Surgery

Mr. H. A. Brittain (Great Britain) reported on the technique and results in a closed method of arthrodesis of the hip, in which a Smith-Petersen nail was used for fixation in the ilium and a tibial bone graft for fixation to the ischium without femoral osteotomy. Walking was possible in two to three weeks, and early fusion resulted. Of thirty-eight patients followed for one year, fusion was obtained in thirty-five.

Dr. Marcel Galland (France) reported on the use of ischiofemoral arthrodesis of the hip in some thirty cases and emphasized the advantage of applying compression on the graft.

Mr. J. Agerholm-Christensen (Great Britain) discussed the treatment of osteo-arthritis and ankylosing spondylitis by excision of the femoral head and neck after the method of Girdlestone.

Dr. J. E. M. Thomson reported on the use of a hip prosthesis in fresh and ununited fractures of the femoral neck in older patients.

Dr. Sven Kiaer (Denmark) gave a preliminary report on the use of the Judet prosthesis in fifty patients with hip disease. No significant difference was noted between cases where the capsule was excised and where it was sutured. Pain was relieved in nearly all patients.

Dr. Knud Jansen (Denmark) reported on experiments with methylacrylic ester implanted in the bones of growing chicks. This caused no bone reaction and was partly soft at 50 degrees centigrade. In Denmark a dental plastic is being used to seal the attachment of the acrylic prosthesis to the reshaped neck. This seems to improve results and causes no harmful tissue reaction.

Dr. Ragnar Magnusson (Sweden) reported the results of subtrochanteric osteotomy for congenital coxa vara in sixty-five cases in a long-time follow-up study. The average age at operation was 10.9 years and at follow-up 27.3 years. Results were better when operation had been performed at nine years of age rather than later.

Dr. Pasquale Del Torto (Italy) discussed the problem of slipping of the upper femoral epiphysis. Treatment was selected according to the stage of the disease. In early slipping, simple elimination of weight-bearing frequently was considered adequate. In the cases with slipping of long duration, only osteotomy to reduce the varus deformity was recommended. In the intermediate stages, reduction and osteosynthesis were advised. The author reported ten cases in which two thin tibial grafts, introduced through the neck from the trochanteric region, were used for fixation.

Dr. Harold B. Boyd reported on a method of determining the blood supply to the femoral neck. A radio-active tracer (P^{32}) was injected intravenously before the operation. At operation counts were made by a special Geiger counter inserted first into the femoral head and then into the trochanteric region. It is hoped that by comparison of these counts the probability of aseptic necrosis may be predicted.

Fractures

Dr. E. Madsen in a study of 117 fractures of the neck of the humerus found seven types, of which he considered these four to be important: abduction fractures with three fragments, 21 per cent.; extension fractures with posterior angulation (seen frequently in the young), 32 per cent.; infractions impacted with little or no displacement, 32 per cent.; adduction fractures with lateral angulation, 8 per cent. With the

exception of the extension fractures, reduction was rarely necessary. Treatment consisted of early mobilization. The extension fracture usually required reduction, which was performed under general anaesthesia, the elbow being carried across the chest almost to the contralateral shoulder while strong traction was applied to the flexed forearm. The arm was then fixed in 50 to 60 degrees of flexion by a plaster spica or cotton pad and bandage. Results were good.

DR. WALTHER EHALT (Austria) recommended primary subastragular arthrodesis of fractures of the calcaneus. Operation was performed within a few days of injury. The astragalus was denuded of cartilage but the os callus was left undisturbed. A wedge of ilium of the same width as the os calcis, two centimeters high posteriorly and 2 to 3 millimeters anteriorly, was then inserted to restore or improve the tuber angle. The foot was kept in plaster for three months, but weight-bearing was started after six weeks. Results were very satisfying, with an earlier return to work.

DR. ERIK MOBERG (Sweden) described a method of treatment for comminuted fractures of the calcaneus. The unsatisfactory results of late arthrodesis were attributed to dense scarring about the joints. Early arthrodesis was recommended to prevent this.

DR. IVAR PALMER (Sweden) reported on animal experiments with dogs to investigate a method of bridging defects in long bones by using an intramedullary nail for fixation, a tubular graft for structural design, and cancellous autogenous chips for osteogenesis. He demonstrated that tubular homografts alone were rapidly absorbed, whereas, if these were supplemented with autogenous bone chips around them, good callus and no resorption of the graft resulted. The method was used successfully in the humerus of one patient.

DR. E. SPIRA (Israel) presented a technique of bridging bone defects in the forearm. After excision of scars and skin-grafting where necessary, all sclerotic bone was excised and a bone graft, either full-thickness ilium or the resected distal end of the ulna, was fixed in place with an intramedullary nail. Bone chips were packed about the graft in some cases. The method has been used in fourteen cases. Of eleven iliac grafts, nine were successful and two failed. Of three ulnar grafts, one failed. In two of the failures there were technical errors. Sepsis developed in three cases.

BONE TUMORS

DRS. JOSÉ VALLS, FRITZ SHAJOWICZ, and SILVANO MONDOLFO (Argentina) reported a study of fifty-five cases of giant-cell tumor of bone. They recommended more radical primary treatment as follows: complete excision of early lesions, provided that loss of function will not result; curettage of small lesions when excision will cause loss of function, followed by packing the defect with cancellous bone; complete excision of advanced recurrent lesions, regardless of functional loss, with later reconstruction procedures. X-ray therapy was reserved for cases in which operation was impossible. Amputation was resorted to in cases with postoperative infection, tumors too large for excision, and lesions which had undergone malignant change. Amputation was not done in cases of primary malignant giant-cell tumors showing favorable evolution after resection.

PROF. F. DELITALA (Italy) showed a moving picture of two cases in which the proximal end of the humerus and distal end of the radius had been resected for tumor and replaced by previously made metallic prostheses.

DR. ADAM GRUCA (Poland) reported twelve cases in which local resection of a malignant bone tumor was possible, and which he had treated by "sterilizing" the tumor with diathermy and leaving it *in situ* as a scaffolding. This was revitalized in six to twelve months.

CHEMOTHERAPY OF TUBERCULOSIS

DRS. SVANTE ORELL, MAC FELLÄNDER, and OLOV LINDAHL (Sweden) reported on their use of chemotherapy combined with surgery. Earlier and more radical surgical treatment was possible with safety. In joint tuberculosis, synovectomy for primary synovial tuberculosis and elimination of a primary bone focus, which perforates a joint, have been followed by good joint mobility in cases where chemotherapy has supplemented surgical treatment. In destructive tuberculous arthritis, joint resection was followed by fusion. In tuberculous spondylitis, radical surgical treatment has been successful in the same way, not only for abscesses, but for bone as well. In the thoracic region approach by costotransversectomy and in the lumbar region by the extraperitoneal route was used. Finally, surgical excision of tuberculosis of the greater trochanter has been successful in cases in which the deep sinus were carefully followed.

PROF. A. CHAKIR CHAKAR (Turkey) reported a six-fold increase in tuberculosis in Turkey since the War. Some 300 cases had been treated with streptomycin as an adjunct to surgery. The drug was used intramuscularly daily and was injected into the focus, when possible, two or three times a week. The sinus responded spectacularly, with 80 per cent. closing in two to six weeks. However, there were recurrences and failures. Early and more radical surgery of tuberculous foci had been used with healing in six to eight weeks in cases in which streptomycin was given locally by tube. Where osteogenesis was inadequate in hip-joint disease, a periosteo-cortico-cancellous graft from the greater trochanter was inserted.

Bone Growth

Prof. J. Trueta (Great Britain) reported on ten children with overgrowth of long bones associated with osteomyelitis. In these cases, as well as in fractures of the shaft with overgrowth, the diaphysis, particularly the marrow cavity, was involved primarily. The nutrient artery appeared to be obstructed. The overgrowth was ascribed to metaphyseal hyperaemia secondary to this obstruction. Similar changes have been produced experimentally on the rabbit's tibia by blockage of the nutrient foramen with wax. The report was preliminary and no conclusions were drawn.

Dr. Hernsson (Sweden) reported on five cases in which arteriovenous fistulae in the femoral vessels in the mid-thigh had been produced to stimulate bone growth. The cases had not been followed long enough to give results.

Other Papers

Dr. P. K. Duraiswami (Great Britain and India) reported some fascinating experiments in which skeletal anomalies in growing chicks were produced by injecting the yolks of hens' eggs with insulin. Abnormalities were produced resembling spina bifida, scoliosis, lobster-claw, club-foot, arthrogryposis, congenital bowing of the tibia, congenital dislocation of the hips and knees, osteogenesis imperfecta, achondroplasia, and dyschondroplasia. Some of these abnormalities were inherited in succeeding generations. These included club-foot and osteogenesis imperfecta. These insulin-induced abnormalities could be prevented by nicotinamide and riboflavin.

Dr. Anders Langenskiöld (Finland) reported fifteen cases of infantile tibia vara and four cases of the adolescent type. In the former, marked angulation was present before three and one-half years of age with one exception. Bilateral osteotomy was performed in seven cases, unilateral osteotomy in seven. Histological section showed irregularity of the bone and cartilage at the bone-cartilage juncture. These changes were interpreted as being due to mechanical strain. In a follow-up study of ten cases of the infantile type, made one to three and one-half years after operation, it was found that when osteotomy was performed before the age of six, correction was maintained, while in the three cases operated on between the ages of nine and one-half and eleven years, there was considerable recurrence of deformity and laxity of the knee joint. In the latter adolescent type, deformity appeared at between eight and thirteen years of age and was unilateral, with one to three centimeters of shortening. Results of osteotomy in this group were good.

Mr. Karl I. Nissen (Great Britain) reported his findings in 100 cases of Morton's metatarsalgia explored by the plantar approach. The changes in the nerve were regarded as secondary to those in the artery. Exploration at various periods after onset revealed thickening and tortuosity of the artery at two months, fibrosis about both the vessel and nerve at three months, and atrophy of the vessel and fibrosis of the nerve at twelve months. In one instance, a cyst of the tendon sheath presented the same symptoms. Both the vessel and nerve were resected.

Dr. J. J. Herbert (France) showed a moving picture of his technique of osteotomy of the spine for Marie-Strümpell arthritis. It was performed in two stages, first posteriorly and then anteriorly, in order to divide the ossified disc and anterior longitudinal ligament.

Dr. Hans Novotny (Norway) reported favorably on results from the transplantation of diseased joint capsules and synovia into the subcutaneous tissues of the abdominal wall in cases of rheumatoid arthritis. He postulated that this stimulated the production of ACTH and cortisone.

General Meeting

At the general meeting, the Secretary-General, Dr. Jean Delchef, reported that Bulgaria, Egypt, Israel, Luxemburg, Mexico, and New Zealand had accepted invitations to become members. He also read the Treasurer's report on behalf of Dr. Charles Parisel, which showed a credit balance, obviating the necessity of an increased subscription. The subscription was to be collected by the delegates in their own countries and was to cover admission to the Scientific Session. The following new Delegates were present: Dr. P. K. Duraiswami, India; Prof. Isaharu Miki, Japan; and Dr. A. Rodo, Portugal. It was voted to readmit the German members.

The following officers were elected:

President: Sir Harry Platt;

Vice-Presidents: Prof. Etienne Sorrel and Prof. José Valls;

Secretary-General: Dr. Jean Delchef with the assistance of Dr. P. Kempeneers and Dr. Van Cauwenberghe;

Treasurer: Dr. Charles Parisel.

Switzerland was selected as the site for the 1954 meeting. Dr. Dubois suggested Interlaken as the best location. Dr. Etienne Sorrel was elected President of the Congress, with Dr. Richard Scherb as Honorary President and Dr. Marcel Dubois as Vice-President. Delegates were requested to submit within a month subjects which their countrymen would like to discuss.

One of the most gratifying and memorable aspects of this Congress was the kindness and hospitality with which the people of Stockholm received the visiting delegates and their families, entertaining them in a fashion never to be forgotten.

Book Reviews

SCOLIOSIS: Pathology, Etiology, and Treatment. Samuel Kleinberg, M.D. Baltimore, The Williams and Wilkins Co., 1951. $7.50.

This is a well written 270-page monograph on scoliosis with an excellent bibliography. The author draws from an extensive experience with his subject.

The book is divided into two sections: the first covers the embryology, anatomy, physiology, pathology, and etiology of scoliosis in a thoroughly adequate manner. Etiology is treated at length. One may take exception to certain presumed causes for functional scoliosis—herein lies one of the numerous attractive features of the book. It stimulates interest.

The second section deals with the treatment of scoliosis and includes an extensive discussion of gymnastic exercises. Operative and postoperative treatment is well presented. The discussion on where to fuse is very short but to the point.

The illustrations—some of them hoary with age—are so adjusted to the text that very little time is lost in checking one against the other.

The reviewer began to read this book, but quickly found himself studying it. It is a well rounded piece of work, provocative in spots, such as the discussion on the use of boiled beef bone. It certainly should be studied by every person interested in scoliosis.

ORTHOPAEDIC SURGERY, Ed. 4. Walter Mercer, M.B., Ch.B., F.R.C.S. (Edin.), F.R.S. (Edin.). London, Edward Arnold and Co.; Baltimore, The Williams and Wilkins Co., 1950. $10.00.

The fourth edition of this excellent textbook has been enlarged and brought up to date. It now numbers 1016 pages as compared with 947 pages in the previous edition. The sections on the metabolic and congenital defects of bone, arthritis, affections of the spine, intervertebral-disc lesions, and the complications of trauma have been completely revised.

The book is organized along pathological lines, which makes for an orderly presentation but perhaps detracts from its value as a reference volume. This is most apparent in diseases of the hip joint. For these, the student must consult widely separated sections of the book, and the index in this instance gives him but little aid.

With some of the author's statements the reader might take issue. For example, the "hyperemic factor" in non-union or delayed union is a rather obscure concept (p. 101). The pathological changes in scurvy (p. 144) appear to be attributed exclusively to hemorrhage with almost no mention made of the failure of formation of intercellular matrix in this deficiency. Many would take exception to pouring 10 per cent. iodine and 95 per cent. alcohol into a wound, even a saucerized osteomyelitic lesion which is to be packed open (p. 200), or to irrigating a septic joint with "saline, mercurochrome or ether" (p. 375). Rheumatoid arthritis is in reality a systemic disease, affecting collagenous structures throughout the body. Only mention of the joint changes in this disease is made (p. 452). Similarly, no note is made of the splenomegaly and hepatomegaly in Still's disease (p. 415). The author devotes five pages to sacralization of the fifth lumbar spinous process with considerable discussion of the technique of operative removal. Many would question the value of this procedure or the validity of considering this an important cause of low-back pain. Most anaesthetists would resent the suggestion of cyclopropane as an anaesthetic when dissection is carried out with diathermy (p. 665). In discussing peroneal or spasmodic flat-foot, the finding of a calcaneonavicular bar is attributed to Harris, while no mention is made of the talocalcaneal bridge which in point of fact is the anomaly which Harris was first to note in his series and, in his series, the most common anomaly (p. 821). Finally, the use of "silver wire", in performing an elbow fusion (p. 917), in these days of stainless steel or tantalum, would seem out of place.

Taken as a whole, however, the book is excellent, well written, and readable. It will prove of great value to both the student and practitioner of orthopaedic surgery.

DIE TECHNIK DER KNOCHENBRUCHBEHANDLUNG. 12. und 13. Auflage. Band I. Dr. Lorenz Böhler. Wien, Wilhelm Maudrich, 1951.

The six years which have elapsed since the eleventh edition of this work have seen no change in Dr. Böhler's basic theory, but there have been many modifications in his practice. This new edition represents an extensive revision of the original work so that, in the author's words, hardly one fifth of the earlier text remains. The present volume benefits from the author's experience with war victims and veterans, as well as from the most recent developments in the use of antibiotics and anaesthetics and in the treatment of shock.

The first part of Volume I discusses the basic principles of treatment. The author takes a strong stand against massage and passive movements. His answer to those who advocate massage in the treatment of the blood extravasations about the fracture is that these clear up spontaneously and in fact disappear more rapidly in those cases in which massage is not undertaken.

Over the years Dr. Böhler's work has grown far beyond the limits set by its title. The present volume includes a section on lesions of the abdominal cavity, uropoietic system, and rectum. The rest of the volume is devoted to fractures and injuries of the skull, vertebrae, and thorax, and to fractures and dislocations of the pelvis, clavicle, scapulae, and upper extremities. There is a detailed study and statistical analysis of hand injuries and a thorough discussion of their treatment according to standard, generally accepted principles. It is hoped that the second volume will discuss more extensively the medullary nailing of Küntscher, especially in connection with fractures of the femur. From the section on delayed callus formation and pseudarthroses in the Volume I, it is evident that the author still believes that medullary nailing delays formation of callus.

Contrary to our former concept, the importance of inducing shortening during immobilization is stressed throughout. To accomplish this it may be necessary in some types of fracture to apply compression instead of traction.

The same thorough-going treatment of the subject which has characterized past editions of *Die Technik der Knochenbruchbehandlung* has been maintained in this volume, which remains a classic. While the author's techniques may not always be applicable to our own problems, we may be sure they have been carefully thought out and are based on a vast experience.

THE AMERICAN ILLUSTRATED MEDICAL DICTIONARY, Ed. 22. W. A. Newman Dorland, A.M., M.D., F.A.C.S. Philadelphia, W. B. Saunders Company, 1951. $10.00.

For fifty years this dictionary has been a standard reference book wherever medicine is studied. The past four years have witnessed many changes in our medical vocabulary. This new edition of Dorland's has absorbed the new terms which have come into use in the various branches of medicine without discarding the older terms which must still have their place.

Two new features of this edition are the tabulation of Modern Drugs and Dosage, prepared by Austin Smith, M.D., which will be of inestimable value to those wishing to keep abreast of the developments in the field of pharmacology; and the section on Fundamentals of Medical Etymology written by Prof. Lloyd W. Daly. This latter section is prepared especially for those not well acquainted with Greek and Latin; it includes an Analytical Word List which shows the combining forms of Greek and Latin words most frequently used in present-day medical literature. Both of these new sections will be welcome to the careful student and will prove of real worth to many who use this Dictionary regularly.

The great care which has gone into the preparation of this new edition is clearly evident. It is a fine piece of work of which the publishers may well be proud.

TECHNIQUES IN BRITISH SURGERY. Rodney Maingot, F.R.C.S., Editor. Philadelphia, W. B. Saunders Company, 1950. $15.00.

Techniques in British Surgery is a collection of articles, written by twenty-nine British surgeons, on diversified subjects, encompassing thoracic, abdominal, genito-urinary, plastic, neural, and orthopaedic surgery. Most of these pertain to such highly specialized fields that the average surgeon will be interested in only a few chapters, but the book would be an excellent addition to a reference library. Five chapters pertain to orthopaedic surgery.

Mr. O. J. Vaughan-Jackson presents a readable and concise discussion of arthrodeses of the hip, the knee, and the ankle which would be especially valuable for the advanced student or resident. It is a well organized survey, systematically discussing indications and contra-indications, surgical principles and procedures. Various methods of arthrodesing each joint are mentioned, with rather full descriptions of the most commonly used techniques, and the author's evaluation of the various methods.

Another chapter concerning basic orthopaedic procedures is that on bone transplantation by Mr. Ian Lawson Dick. This includes a short historical summary of the progress of bone-grafting, physiological considerations, and indications for transplantation of cortical and cancellous bone. The various types of bone transplantation are described briefly and illustrated by photographs of drawings and roentgenograms.

The treatise on "Recurrent Dislocation of the Shoulder" by M. J. Crawford Adams is as clear and concise as any written in the current medical literature. In logical steps are described the mechanism of injury, evolution of our knowledge of the pathology of recurrent dislocations, indications for operation, and the detailed steps in the surgical repair. This chapter alone makes the purchase of the book worth while.

Mr. Denis Browne outlines his method of treatment of congenital dislocation of the hip, giving the reasons for this method based on his conception of the cause of the condition. He makes the correction sound simple, far simpler than it has been found to be by most of those who have had experience in treating this condition.

The chapter on talipes by Mr. Denis Browne will not be highly acclaimed by most orthopaedic surgeons in this country. He advocates "drastic manipulations", so forceful that complete overcorrection is often accomplished at the first manipulation, and decries the method of gradually pulling the foot around. He states that plaster-of-Paris should be avoided in the young infant because "it is kicked off if put on loosely, and can produce appalling disasters if put on tightly". Many of the views expressed are at variance with the standard practice of gradual correction by the use of club-foot plasters so commonly and successfully used in America.

ANATOMY IN SURGERY. Philip Thorek, M.D., F.A.C.S., F.I.C.S. Philadelphia, J. B. Lippincott Company, 1951. $22.50.

This book should appeal to the young surgeon and to the student of anatomy, because both will find it easier to remember important anatomical details and surgical considerations after having read it.

Differing somewhat from most books on surgical anatomy, this book correlates surgical techniques with anatomy instead of covering each separately.

This author divides the body into the following segments: the head; the neck; the thorax; the abdomen; the pelvis; the male and the female perineum and external genitalia; the superior extremity; the inferior extremity; and the vertebral column, canal, and spinal cord. With each segment, he presents methods of approaching operatively its various components. Many other important approaches and incisions are also outlined.

Dr. Thorek's style of writing is clear and stimulating. He has the peculiar knack of finding the word, or the simile, which is unique, yet easily understood.

All of the illustrations, which were drawn by Carl T. Linden of the University of Illinois College of Medicine, are well done and carefully reproduced. Large lettering enables the reader to identify the details of each drawing readily.

In *Anatomy in Surgery*, Dr. Thorek has accomplished his purpose, as set forth in the Preface, of narrowing the gap which exists between freshman anatomy and operative surgery.

OPERATIVE SURGERY. Edited by Alexander Miles, M.D., L.L.D., F.R.C.S. (Ed.) and Sir James Learmouth, K.C.V.O., C.B.E., Ch.M., F.R.C.S. (Ed.). Ed. 3. London, Oxford University Press, 30 shillings; New York, Oxford University Press, 1950. $6.50.

This volume, the various sections of which were written almost entirely by members of the University of Edinburgh Faculty of Medicine, is designed to meet the requirements of fourth-year students, interns, and residents. The thirty-three sections cover all anatomical areas and all specialties, save only the surgery of the central nervous system.

The general principles of every surgical problem are considered, and the operation preferred by the Edinburgh school is outlined.

The manner in which the surgical procedures are outlined varies in detail among the several authors—some of the operations are outlined so completely that they could be performed by the novice without recourse to any other text, while others are outlined in general principles only. Preoperative and postoperative care are touched upon; and, for the most part, the techniques presented are up-to-date and should be satisfactory. However, there are several procedures which surgeons on this side of the Atlantic would view with some surprise or misgiving. This reviewer, for instance, was surprised to find the flap operation devised by Warbasse for the repair of syndactylism the only method advised.

A major lack is a bibliography, particularly since the book is designed for students. It might also have been better to mention alternate methods of therapy.

It is doubtful that American students of surgery would find this volume very helpful.

MEISTER DER CHIRURGIE UND DIE CHIRURGENSCHULEN IM DEUTSCHEN RAUM. DEUTSCHLAND, ÖSTERREICH, DEUTSCHE SCHWEIZ. H. Killian und G. Krämer. Stuttgart, Georg Thieme Verlag, 1951. DM 24.80.

This attractively printed and illustrated monograph on the history of surgery and surgeons in German-speaking countries is an item for the collector. The account of the development of German surgery, beginning with the barber-surgeons, tooth extractors, and "cuppers" of the Middle Ages, will interest physicians in all fields.

The final section of the book consists of genealogical charts listing the masters of German surgery and the future masters who studied under them; throughout, there are excellent portraits and reproductions of the historic seals of the chief universities. The material is arranged geographically, with brief sections on the larger medical schools and brief biographies of the eminent surgeons in each city.

This book is invaluable to all interested in the historical background of surgery.

LEIBESÜBUNGEN MIT KÖRPERBESCHÄDIGTEN. Hans Lorenzen. (Arbeit und Gesundheit, neue Folge Heft 45.) Stuttgart, Georg Thieme Verlag, 1951.

Written for physical therapists and others who work with the disabled, as well as for the handicapped themselves, this volume provides a useful addition to the literature on rehabilitation. The psychological as well as the physiological value of regular exercise is stressed throughout, as is the importance of group work for the handicapped and their competition with each other.

A brief section on exercising the "phantom limb" will be found of particular interest. The author, who appears to be an amputee himself, advocates massage and exercise for stumps, and in particular recommends exercises in which the amputee attempts to exercise the sound limb and the phantom limb simultaneously; in the phantom limb there will be a sensation of resistance or of delayed response. Strengthening the stump will, he believes, remedy many of the neurological as well as the circulatory and muscular disturbances arising within it.

Swimming and diving are stressed as among the most valuable forms of exercise for the disabled.

There are numerous illustrations and a selected bibliography, chiefly of works in German.

PROCEEDINGS OF THE SECOND CLINICAL ACTH CONFERENCE. 2 Vols. Edited by John R. Mote. Philadelphia, Blakiston Company, 1951. $8.50 per volume.

There are two volumes, edited by Dr. John R. Mote, which include the 102 papers and numerous discussions of these reports which were read at the Conference held in Chicago in December 1950 under the auspices of the Armour Laboratories.

The first volume, entitled "Research", deals primarily with the more fundamental aspects of ACTH and adrenal cortical function, as well as the effects of adrenal corticoids on different tissue systems under varying physiological and metabolic conditions. The papers cover many aspects of the problem, including the influence of ACTH on renal function and electrolytes; the metabolism of carbohydrates, fat, nitrogen, and vitamins A and C; the liver; plasma iron; the hemopoietic system; and inflammatory and allergic reactions.

The second volume, with the title "Therapeutics", records the experiences of many with the use of ACTH in the treatment of a wide variety of diseases, as well as the technique of therapy, including the use of long-acting ACTH. Most of the papers are in the nature of preliminary or progress reports. The vast number of diseases considered indicates the tremendous amount of work being done. For example, this volume includes papers on the use of ACTH in such varied conditions as hypoglycaemosis, congenital adrenal hyperplasia, hypothyroidism, gout, myasthenia gravis, multiple sclerosis, certain anaemias, nephrosis, leukaemia, multiple myeloma, black-widow-spider and rattlesnake bites, acute burns, skin-grafting, ocular trauma and diseases, postoperative shock, tenosynovitis, tendinitis of the shoulder, tuberculosis, blastomycosis, typhoid, beryllium granulomatosis, silicosis, allergy, ulcerative colitis, regional enteritis, Hunner's ulcer, the so-called collagen diseases, and even the shoulder-hand syndrome.

As might be expected, much of the work reported is inconclusive and in its preliminary stages. However, there is much to suggest that these hormones have wide applicability. Although they are not specific and seldom produce lasting effects, they would appear to be potent therapeutic adjuvants, not only in many of the collagen and ocular diseases, but also in the bites of some venomous insects and snakes, in leprosy, and in typhoid fever, to mention but a few.

These two volumes, compiling as they do the recent work of the foremost workers in the field, provide fascinating and tremendously stimulating reading.

PHYSIOLOGY OF SHOCK. Carl J. Wiggers, M.D. New York, The Commonwealth Fund, 1950. $5.00.

Shock has proved to be as baffling to the scientist as it is interesting and important to mankind; a vast amount of experimental work on this subject has accumulated. For most of his scientific career, Prof. Wiggers has been a close student of the shock problem and a frequent contributor to its literature. Under his direction, for many years investigations of the phenomena of shock and of variations in the peripheral circulation constituted the greater part of the research program of the Department of Physiology of Western Reserve University.

This book is a record and critical analysis of these studies as well as of the significant experimental work pertaining to shock which has been done elsewhere. In a word, this book includes the present-day accredited body of knowledge of shock as it has evolved from laboratory experimentation.

In a sense, Prof. Wiggers' book *Physiology of Shock*, presenting the laboratory experimental approach, and Prof. Beecher's *Resuscitation and Anaesthesia for Wounded Men* (reviewed elsewhere in this issue of *The Journal*), depicting the practical approach of the clinician, are companion volumes.

The first chapter presents a general analysis of the various approaches to the shock problem. The patterns of laboratory investigation and their objectives are then unfolded. Next, the clinical signs and symptoms are surveyed. There then follow detailed treatments of the work in experimental shock, in the hemo-

dynamics of shock, on mechanisms of peripheral circulatory failure, on the heart in shock, on the respiratory and oxidative functions, metabolic disturbances, toxaemic and neurogenic factors, to each of which subjects the author devotes a chapter.

To the thorough-going student and teacher of this subject, this book of 459 pages will prove an invaluable reference.

RESUSCITATION AND ANAESTHESIA FOR WOUNDED MEN. The Management of Traumatic Shock. Henry K. Beecher, M.D. Springfield, Illinois, Charles C. Thomas, 1950. $5.50.

This book of 151 pages of text is essentially a book of practice. It is a compilation of articles recorded from the author's exhaustive experience while investigating resuscitation at the front during the thirty months of the Mediterranean Campaign and published during the years 1944–47 in various surgical periodicals. Long a student of shock and given unrestricted opportunity by the Army to observe and investigate during the entire campaign, the author has produced a book which is destined to serve as an authoritative guide for the proper care of the patient during "the crucial interval that exists from the time [of injury] until the surgeon repairs the wound . . ." not only in civilian practice but on the mass scale encountered in war or civil calamity.

"Several innovations" in management as well as "new general practices" are presented. In each instance, these arose from the trained observations of the author on single patients, later to be carefully checked on groups of patients, and, finally, their validity confirmed through constant sampling of great numbers of wounded.

There are four sections, each devoted to a major aspect of the subject. Section I treats of the wounded man—his mental and physical state; Section II of the physiological derangements in the wounded, found upon his admission to a forward hospital; Section III, treatment; and Section IV, anaesthesia.

The presentation is a model of conciseness.

It meets an urgent need completely. Every surgeon even remotely concerned with the surgery of injury should master the details and principles of this book.

DIE CHIRURGIE DER POLIOMYELITIS. Dr. med. Helge Sjövall. (Chirurgie in Einzeldarstellungen, Band 46.) Berlin, Walter de Gruyter und Co., 1951. DM 13.80.

Chirurgie der Poliomyelitis offers an excellent brief summary of present operative principles and methods in poliomyelitis. The author begins with a short introductory survey of the history, etiology, and epidemiology of the disease. The section on operative treatment which follows includes a general discussion of such problems as treatment of shock, anti-tetanus measures, use of antibiotics, and types of anaesthesia.

The author never loses sight of the general principles of treatment. He stresses the psychological value of such procedures as electrical therapy—although the trend in Sweden is away from this form of treatment—and the hot packs of the Kenny method, even if the physiological effects of the latter are negligible.

American readers will be interested in the discussion of the principle of arresting epiphyseal growth in cases where equalization of length is necessary. The author believes that arrest of bone growth is indicated only in certain carefully selected cases, since there are too many individual variations in the rate of growth and since there is always the danger of asymmetrical fusion.

There is an index and a selected bibliography.

A SYLLABUS OF LABORATORY EXAMINATIONS IN CLINICAL DIAGNOSIS. Critical Evaluation of Laboratory Procedures in the Study of the Patient. Thomas Hale Ham, B.S., M.D., Editor. Cambridge, Harvard University Press, 1950. $5.00.

This syllabus, prepared by Dr. Ham and his associates, is dedicated "to those medical students whose enthusiasm and inquiry stimulated its publication". Thirty-three different authors contributed to this volume, many of them experts in their particular fields; twice that number passed critical judgment upon it before its publication.

The importance of adequate laboratory examinations is recognized. Upon these data, as well as upon the statements of the patient and the physical examination, is based the preliminary diagnosis. The responsibility for complete and accurate examination rests with the physician in charge, and the establishment of an accurate diagnosis determines the prognosis and treatment. This book offers many suggestions for the organization of this phase of his work.

The volume includes the best methods of laboratory examinations in use in clinical pathology at the present time. The largest section is devoted to laboratory examinations of the blood; other chapters deal with tests related to the urinary system, the gastro-intestinal tract, diseases of metabolism, infectious diseases, and extravascular fluids. The significance and evaluation of each of the tests are included; this feature will be of value to the clinician in whatever field of medicine.

The format is not attractive and the type matter is difficult to read, but this offset lithography was chosen as a medium because it assured a low-price publication which could be available to many laboratory workers.

This volume is indispensable to those working in this field, not only for the definite instructions given, but also for the interpretation of the results obtained by the methods described. It is valuable not only for clinicians in the younger group, but especially for those whose graduation from medical school antedated the present laboratory procedures.

The quantitative methods of study of the blood are included in this syllabus, but the study of the morphology of the blood is covered in a companion volume, *Color Atlas of Morphologic Hematology*. Both volumes are essential for every clinical laboratory.

COLOR ATLAS OF MORPHOLOGIC HEMATOLOGY. With a Guide to Clinical Interpretation. Geneva A. Daland, B.S. (Edited by Thomas Hale Ham, M.D.) Cambridge, Harvard University Press, 1951. $5.00.

This *Color Atlas* is a companion volume to *A Syllabus of Laboratory Examinations in Clinical Diagnosis*. It is a practical guide for the student, the technologist, or the physician who wishes to study blood films in various conditions.

The characteristics of the cell structure are emphasized, since these details are important in differentiating the type of cells and the stages of development. The diagrams illustrating the maturation of the cells of each series are especially valuable.

The method of study of the blood film presented is the result of the author's many years of experience in teaching hematology. Practically all the cells seen in normal and abnormal blood films are represented in the color plates.

These fourteen color plates, accurately reproduced from original water colors, so ably executed by Etta Piotti of the Harvard Medical School, are invaluable, since they represent many typical disease states. The discussion of these plates brings out many points of value in the differential diagnosis of these conditions. The cells of each plate are identified and the laboratory data are given.

This book is unique in its arrangement, exceptional in the number and quality of the color plates, and of definite practical value to the beginner as well as to the experienced worker in this field.

THE ANATOMY OF THE GORILLA. (The Henry Cushier Raven Memorial Volume.) Edited by William King Gregory. New York, Columbia University Press, 1950. $15.00.

H. C. Raven, Curator of the Department of Comparative Anatomy of the American Museum of Natural History, at the time of his death was engaged in a detailed study of the anatomy of the gorilla.

This volume contains his notes and a wealth of the most exquisite illustrations, most of them pen-and-ink sketches. The volume is made complete by contributions from some of Raven's colleagues and by excellent arranging and editorial work by W. K. Gregory.

This book will undoubtedly stand as the definitive work in its field. The anatomy of the gorilla is so similar to that of genus homo that many of the illustrations look almost identical with those in standard texts on human anatomy.

The student of comparative anatomy will find this volume indispensable; it is also a thing of beauty—a collector's item.

FUSSGYMNASTIK MIT KINDERN. Martha Scharll. Stuttgart, Georg Thieme Verlag, 1951. DM 2.90.

Photographs form the main content of this little booklet, which will be welcomed especially by teachers and physical therapists. Most of the exercises here presented are not planned for special pathological conditions so much as for general prophylaxis. As much as possible, the exercises are designed to be "games" for children. The brief, vivid captions which accompany the photographs are non-technical and are evidently intended for parents who wish to cooperate with the physician and at the same time to make corrective exercises a pleasant experience. The pamphlet represents a novel and refreshing approach to an important but too often boresome form of therapy.

GROWTH AND DEVELOPMENT OF CHILDREN. Ernest H. Watson, M.D., and George H. Lowrey, M.D. Chicago, The Year Book Publishers, Inc., 1951. $5.75.

Here is a practical handbook for those who are concerned with the care and treatment of children; concise, graphic, and comprehensive, it adeqately reviews the field.

One of the merits of the book is the accessibility of the material and the logical and orderly presentation of facts; the dynamic, physiological, and psychological changes which take place from conception to maturity are taken up in sequence. There is a brief but pertinent discussion of the influence of the factors of heredity and environment; then follows a discussion of the foetal growth and development, gross body measurements,

and a thoroughly interesting chapter on behavioral development. This is followed by a review of the development of specific organs and the development of the skeletal system. After dealing with certain problems of metabolism and nutrition in normal growth, the book closes with a brief chapter entitled "An Outline of Abnormal Growth". Here the authors limit themselves to a discussion, primarily, of the aberrations of statural growth occurring in infancy and childhood.

Each chapter is concluded with a fairly extensive bibliography. The authors have not tried to be comprehensive in these but have listed the newer works in journals and periodicals which are easily obtainable. Rarely is the foreign literature cited.

The book will be helpful to undergraduates in medicine, residents, and practitioners alike.

VERHANDLUNGEN DER DEUTSCHEN ORTHOPÄDISCHEN GESELLSCHAFT. Achtunddreissigster Kongress. (Beilageheft der *Zeitschrift für Orthopädie*, Band 80). Stuttgart, Ferdinand Enke, 1951.

This supplement to the *Zeitschrift für Orthopädie* provides an excellent survey of recent progress in German orthopaedics. The main themes discussed at the *Kongress*, which was held September 14 to 16, 1950, include such topics as the effect of local circulatory disturbances on diseases of bone, treatment in osteo-articular tuberculosis, and theory and practice of massage. An essay on the etiology of congenital defects and a study of 236 pairs of twins with congenital dislocation of the hip should be of especial interest.

Those who through the years have followed German orthopaedic literature will find it a source of great satisfaction to have these annual presentations available once more.

PRIMER ON FRACTURES. Ed. 6. Prepared by the Special Exhibit Committee on Fractures in Cooperation with the Committee on Scientific Exhibit of the American Medical Association. New York, Paul B. Hoeber, Inc., 1951. $2.00.

The *Primer on Fractures* is intended for the ready-at-hand use of the practitioner. The principles of the treatment of fractures are those presented at the Fracture Exhibit of the Annual Meeting of the American Medical Association and are here given in as concise and simple a form as possible, with a large number of uncomplicated drawings. Besides sections dealing with the reduction and treatment of the different types of fractures, there are short discussions of emergency first-aid splinting, of the preparation of plaster-of-Paris bandages, and of massage and active movement in the treatment of fractures. The book concludes with suggestions for splints and accessories to be kept in the doctor's office and car.

DEGENERAZIONE E RIGENERAZIONE DEI TRONCHI NERVOSI NELL' UOMO. Prof. Silvano Leghissa. Bologna, Edizioni Scientifiche Istituto Rizzoli, 1950. L. 4,500.

This monograph, presented in concise Italian diction, is the work of an anatomist as well as of a clinician.

The first chapter deals with the mechanism of regeneration in general, starting with the Wallerian concept of the total regeneration of the peripheral end. There is ample reference to preceding contributions, particularly to that of Ramon y Cajal, who first demonstrated that regeneration occurs from the central axis cylinders and proceeds into the distal trunk, in contrast to the older concept of autogenous or peripheral regeneration. Collaterals and spiral whirls are described in connection with the fact that Wallerian degeneration is not progressive but starts simultaneously in all parts of the peripheral trunk.

The second chapter, starting with the concept of His and Forel, deals particularly with the neuron as a morphological unit, which is described in detail together with all its connections to the tracts of the spinal cord. The intensity of the regenerative capacity of the neuron on an experimental basis is discussed.

Regarding the reaction of the neuron itself to the mutilation of the axis cylinders, the author shows that the first two constituents to react are the Nissl bodies and the neurofibrils of the motor cells.

Chapter 3 is a minute description of the three types of nerve fibers,—the sympathetic, the cerebrospinal, and the peripheral somatic.

Although most of the facts about the peripheral nerve are generally known, they are here exceedingly well demonstrated. This chapter, well supported by schematic drawings, is particularly helpful to the understanding of the minute construction of the nerve fibers. Especially interesting are the illustrations of the fibrillary structure of the axis cylinders which are shown under ultraviolet light.

In the description of the neuromuscular end plate, the double functional termination of the somatic and the vegetative systems is discussed, following the work of Boeke.

In Chapter 4, the author speaks of the ratio between the nerve fibers and the connective tissue contained in the peripheral nerve. He emphasizes that repair does not depend upon the axis cylinders alone but also upon the connective tissue, that the connective tissue increases from the central to the peripheral portion of the nerve, and that the size of the neuron is directly proportional to the area of the innervated periphery. Experiments on lizards have shown that amputated limbs are regenerated from the last three pairs of the spinal nerves.

The relation of the nerve fibers to connective tissue, one of the principal subjects of the work, has been determined by the author for the different levels of the radial, median, ulnar, sciatic, tibial, and peroneal nerves. He shows that the percentage of nerve fibers in all of these decreases from the central to the peripheral in favor of the connective tissue. Furthermore, the proportion of connective tissue increases constantly with age, ranging from 54 per cent. in infants to 82 per cent. in the aged.

The subject of Chapter 5 is the histological reaction of the nerve trunk after being sectioned and descriptions of the neuroma, the glioma, and the distal fibroma.

Chapter 6 considers the reaction of the neuron to the mutilation of its axis cylinders. The degenerative changes in the anterior horn cells are well illustrated. Furthermore, the differences in the degeneration of the nerve fibers according to the level of sections, alteration of the myelin sheath, the effect on Schwann's sheath, and the total disappearance of the somatic and sympathetic fibers in the peripheral trunk are described.

Chapter 7 and Chapter 8 are devoted to the matter of connective-tissue reaction of the nerve trunk following the development of lesions in man. The importance of connective tissue in the regeneration of the nerve is emphasized again; the actual process of connective-tissue reaction and the influence of the axis cylinders upon such reaction is discussed.

The clinical application of these extensive anatomical studies is introduced in Chapter 9. The behavior of transplants in the functional regeneration of the nerve is the main topic.

The author considers the autoplastic, the homoplastic, and the heteroplastic transplants. The autoplastic transplant is the most successful for reneurotization, while the homoplastic and heteroplastic transplants are almost uniformly unsuccessful. This is demonstrated in great detail by photographs of histological slides showing both the proximal and distal ends of the nerve implant. There is a difference in the autoplastic transplant according to whether it is transplanted while fresh or has been prefixed in alcohol. When the fresh specimen is used, Schwann's sheaths persist as conductors of the central axis cylinders; when, however, the prefixed transplant is used, Schwann's sheaths may at first serve as conductors but are soon replaced by newly formed sheaths which come from the proximal end of the nerve.

Chapter 10 deals with the regeneration of the musculospiral nerve. It is of interest to learn that the regeneration rate is related to the level,—that is, the axis-cylinder push is greatest, the more central is the lesion. On the other hand, the time period in which successful repair must be accomplished increases from the central to the distal portion of the nerve. For instance, for the musculospiral nerve, it is six or seven months in the upper third of the arm and fifteen months in the lower third of the forearm.

The median nerve is the subject of Chapter 11. While this nerve has approximately the same diameter as the radial, it has a relatively greater amount of connective tissue and, therefore, a lesser tendency to regeneration. Here also, the more proximal the lesion, the sooner the repair must be undertaken. The time taken for regeneration is from six months in the upper third of the arm and from ten to eleven months for the forearm.

Chapter 12 is devoted to the ulnar nerve which is most refractory to regeneration. This, the author finds, is due to the morphological characteristics of its neuron, as well as to an overwhelming quantity of connective tissue. Here also, the higher the lesion, the greater is the degenerative force but also the shorter is the time interval in which regeneration is possible. Analogous findings are given for the sciatic nerve in Chapter 13, and for the peroneal nerve in Chapter 14. The author finds the peroneal nerve particularly resistant to regeneration.

Chapter 15 deals with the indispensable condition under which regeneration is possible. The author points out that spontaneous regeneration does not occur. End-to-end junction is absolutely necessary.

He speaks in Chapter 16 of the histological mechanics of regeneration and repair, and in Chapter 17 he opens with the question of whether or not repair should be done early or late. He concludes that a spontaneous nerve repair can only be thought of in cases in which there is only a partial lesion of the trunk and that in all complete lesions operative intervention is always necessary. Further, the author is inclined to advocate early repair and believes there is no advantage in delay.

The whole book is profusely and splendidly illustrated, and it contains an extremely broad background of experimental work. It is excellently elaborated from the anatomical and pathological points of view. In addition, the author is most painstaking in the analysis of the clinical situations and in the therapeutic implications based upon morphological and physiological studies. One will find the book a mine of useful information in the field of peripheral-nerve surgery. It is a classic of its kind.

THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS, INSTRUCTIONAL COURSE LECTURES, 1951. Volume VIII. Charles N. Pease and Sam W. Banks, Editors. Ann Arbor, Michigan, J. W. Edwards, 1951. $8.50.

The Instructional Courses given at the Annual Meeting of The American Academy of Orthopaedic Surgeons, held in Chicago in January 1951, were received with enthusiasm. It is not strange that this Volume combining papers selected from these Instructional Courses should be an outstanding volume. Some of the papers are published in essentially the same form as presented by the lecturer and are well illustrated; others are presented in abstract. Many of the instructors of these courses have previously lectured or written on the subjects assigned to them. It is natural, therefore, that much of the material is not new. Rather, these men

have presented reviews of these subjects. These reviews were appreciated by those who were permitted to take the courses and will prove valuable to those who read this volume.

One special feature of the Lectures this year was the section devoted to the subject of Medullary Fixation of the Femur. In 1947, the Department of the Army authorized a grant through the National Research Council for the extensive clinical investigation of the results of medullary fixation of the femur, as the technique has been carried out by different surgeons in different medical centers. The Committee on Fractures of the Academy also chose medullary fixation as a project for clinical investigation.

The symposium published as Chapter I, under the leadership of Dr. Hugh Smith of Memphis, presents some of the findings of this investigation. It reports the combined experience of numerous surgeons in 700 medullary nailings of the femur, performed in different hospitals throughout the country. This section will be of inestimable value to all doing this type of surgery.

Chapter II includes a series of papers on cortisone and ACTH, as presented by a group of surgeons from the Mayo Clinic, where such outstanding work has been done.

Slightly different paper is used for this year's volume, and the glossier finish affords better reproductions of the illustrations and a more attractive volume.

The Editors are to be congratulated on the fine piece of work.

ESSAYS IN SURGERY. Presented to Dr. W. E. Gallie on the Occasion of His Retirement from the Chair of Surgery in the University of Toronto. Toronto, the University of Toronto Press, 1950. $9.50.

The forty-three essays brought together in this volume were written in 1947 to mark with honor the occasion of Dr. Gallie's retirement. The essays are devoted to no one branch of surgery; rather are they representative of surgery as a whole. In many instances, the essays are the result of Dr. Gallie's examples and teachings; indeed, the very diversification of the material included emphasizes the fact that, while Dr. Gallie was largely interested in orthopaedic surgery, he zealously avoided overspecialization.

These essays, diverse though they may be in topic, combine to make a well rounded, valuable volume,—a review, perhaps, of modern surgical thought and practice. The student and the practitioner will find this feature of the book especially valuable.

The collection begins with a short biographical notice of the life and career of Dr. Gallie, together with a complete listing of his contributions to medical literature. The volume itself is compact, well printed, and superbly illustrated. It is a worthy tribute to Dr. Gallie.

SURGICAL FORUM. Proceedings of the Forum Sessions; Thirty-sixth Clinical Congress of the American College of Surgeons, Boston, Massachusetts—October, 1950. Philadelphia, W. B. Saunders Company, 1951. $10.00.

In 1941, the Forum on Fundamental Surgical Problems was introduced as part of the annual Clinical Congress of the American College of Surgeons. The purpose of this Forum was to provide an opportunity for younger men who had been doing research in the field of surgery to present their findings to experienced surgeons who would appreciate the problems faced, evaluate the methods of study and approach, and correctly estimate the value of the results obtained.

The success of the Forum has been outstanding. Through this portion of the program, the Fellows of the College whose present duties do not allow time for research have been kept in touch with the work of the younger men in this field. Moreover, these younger men who have faced these problems with new methods of solution and have carried on this interesting research have been given opportunity to have their work approved by men most capable of judging it. As a result, they have received from these more experienced surgeons suggestions for further study and encouragement in their work.

So far, much of the value of the Forum has been limited to those who are able to attend. With this volume is initiated the plan of making the reports available to others. This first volume represents some of the most important work presented at the Forum in connection with the Clinical Congress held in Boston in October, 1950. Some of the papers appear to be in much the same form as they were presented, with illustrations. Other papers have been presented in the form of abstracts, or only summaries of the findings have been included.

This book will be valuable to all who are anxious to know of the newer research in the field of surgery. It is hoped that the response to the first volume will justify its continuance as an annual publication.

MULTIPLE SCLEROSIS. APPLICATION OF REHABILITATION TECHNIQUES. Edward E. Gordon, M.D. New York, National Multiple Sclerosis Society, 1951.

The object of this monograph is to state that much can be done, beyond diagnosis, for the patient suffering from multiple sclerosis through the application of rehabilitation techniques. One of the most important tools in such rehabilitation is neuromuscular re-education. Through this, as well as through a spirit of hope-

ful management, the patient can be taught "how best to live with his disabilities and how best to exploit residual capacities". Thereby the patient's life may be made productive, or self-dependent, or, at the very least, tolerable.

The pamphlet is divided into four main sections: The first deals with the possibilities and limitations of rehabilitation procedures. In this it is emphasized that the pathological process in the central nervous system cannot be altered by rehabilitation procedures and that it is hoped that through these rehabilitation procedures remaining functions may be enhanced and utilized to bring the patient to some degree of self-sufficiency. The second section presents a system for the evaluation of disabilities; and the third outlines concisely a program of rehabilitation. The fourth section is by far the longest and most detailed; it deals with treatment. In it the various disabilities brought on by the disease are evaluated and a program of treatment is outlined. Treatment with drugs and surgery is touched upon, although greater emphasis is placed upon the methods of physical therapy.

The pamphlet concludes with an appendix devoted to a table illustrating the causes of death and charts for the evaluation of disabilities and of exercise programs. There is also an extensive bibliography of the literature.

LEG AMPUTEE: PRE-PROSTHETIC TRAINING (Rehabilitation Series: No. 3). Signe Brunnstrom and Donald Kerr. West Orange, New Jersey, The Kessler Institute for Rehabilitation, 1951.

This excellent pamphlet, the third in The Kessler Institute's Rehabilitation Series, is designed to help the recent leg amputee through the difficult period of personal and physical rehabilitation between the time of amputation and the fitting of the prosthesis. It deals with the subjects of early aftercare, bed exercises, bandaging the stump, the use of crutches, the care and strengthening of the remaining leg, hopping technique, general conditioning, and specific stump exercises. Illustrations, clear and self-explanatory, are the means of instruction; the text is kept to a minimum, merely explaining the figures.

This should be a very helpful pamphlet for the recent leg amputee; it will clearly put before him what he must do for himself physically to fit himself for the restoration of function provided by the prosthesis.

LA TORSION TIBIALE. SA MESURE—SON INTÉRÊT CLINIQUE, RADIOLOGIQUE ET CHIRURGICAL. Paul-Victor Dupuis. Liege, Editions Desoer; Paris, Masson et Cie., 1951. 920 fr.

"Adaptation to the bipedal stance takes place through the intermediation of skeletal torsion." With this as his theme, Dupuis has been engaged in the study of tibial torsion since 1931. This monograph, which contains the results of his study, is based on the mensuration of anatomical specimens, both infantile and adult, on the sequence of torsional changes which are characteristic and normally occur in different age groups, on hundreds of clinical examinations, and on a careful study of abnormal torsion, especially in cases of congenital equinovarus.

Like other students of the subject, Dupuis carefully differentiates between rotation of the limb as a whole and torsion occurring within the limb. He notes that in 80 per cent. of the new-born, the relationship between the bimalleolar axis and the bicondylar axis varies from 10 per cent. of internal torsion to 10 per cent. of external torsion with an average value of 2 degrees, 11 minutes. Normally, the gradual transition from internal torsion to the adult external torsion of about 20 degrees occurs up to the ages of six to ten years. Any notable retardation in this process constitutes an indication for treatment.

In congenital club-foot, internal torsion is not uncommon. As is widely known, it is the responsible factor in the unsatisfactory results observed in recurrent or inadequately treated patients. If recognized early, complete cure can be obtained within nine months by means of a plaster-of-Paris cast, applied with the knee in flexion of 90 degrees. When unsuccessful, or in late cases, correction may be obtained by means of a torsional osteotomy.

This monograph is particularly valuable for the tables of actual measurement it presents. Simple methods for the measurement, both clinical and instrumental, of torsion in the infant and adult are described. It would seem, however, that the tropometer, illustrated in Figure 17, would give more accurate clinical results if the axis of the indicator were shifted slightly in order to become collinear with the inner edge rather than with the mid-line of the fixed arm of the apparatus.

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